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"FINE-SCALE STRUCTURE IN THE FAR-INFRARED MILKY-WAY"

Issued by : NASA Goddard Space Flight Center

Contractor: StarStuff Incorporated (Fed ID #91-1478406)

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ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

FINAL REPORT ON CONTRACT

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for period ending June 30, 1995

This report summarizes the work performed over the official funding period (February 1, 1994 to January 31, 1995) plus an unfunded period ending June 30, 1995. The work carried out falls into five broad categories: (1) generation of a new dataproduct (mosaics of the far-infrared emission in the Milky Way), (2) acquisition of associated dataproducts at other wavelengths, (3) spatial filtering of the far-infrared mosaics and resulting images of the FIR fine-scale structure, (4) evaluation of the spatially filtered data, (5) characterization of the FIR fine-scale structure in terms of its spatial statistics, and (6) identification of interstellar counterparts to the FIR fine-scale structure. These work categories are described in the following six sections. In the Appendix, we include a related article written for a symposium on infrared cirrus and diffuse interstellar clouds.

1. Mosaics of the Far-Infrared Emission in the Milky Way

We have generated, evaluated, documented, and archived a new dataproduct which represents a significant improvement over previous related dataproducts. In May 1995, a data tape for archiving at the National Space Sciences Data Center was hand-delivered to the office of Dr. David Leisawitz. The exabyte tape contains 32 mosaic images of the far-infrared emission from the Milky Way. These images comprise the major "deliverable" resulting from the ADP proposal "Fine-Scale Structure in the Far-Infrared Milky Way" (W. H. Waller, P.I.) as implemented through NASA Contract #NAS5-32591 to StarStuff Incorporated.

The data tape contains 8 mosaic images for each of the 4 IRAS bandpasses (12, 25, 60, and 100 microns). The 8 contiguous mosaics are separated by 45° in Galactic longitude, with approximate dimensions of $60^\circ \times 60^\circ$ in longitude and latitude at a pixel scale of $0.05^\circ \times 0.05^\circ$. In this way, the entire Milky Way is covered with overlaps of approximately 7.5° between images. The value of each pixel is in units of MJy/Sr.

The mapping projection of each mosaic image is gnomonic (tangent plane), mean-

ing that lines of constant longitude are straight and mutually parallel, while the lines of constant latitude bow in towards the center (see **Figure 1.1**). The total range in latitude changes from $\pm 29.5^\circ$ through the center of the image to $\pm 27.9^\circ$ along the sides. Re-projection to rectangular or other coordinate systems can be done using image processing routines in IDL, AIPS, IRAF or equivalent astronomical software packages. If only one or two mosaics at a different projection is desired, we recommend that the investigator use the *SkyView* "advanced" interface on the World Wide Web. Its URL is (<http://skview.gsfc.nasa.gov/skyview.html>).

The FIR mosaics were made from the IRAS Sky Survey Atlas (IRAS/ISSA) images, and so represent a culmination of the latest processing of the IRAS data (Wheelock *et al.* 1994). The re-processing involved co-addition of the individual HCON images, de-striping on multiple scales, and removal of the zodiacal emission component. The resulting mosaics have considerably higher S/N than the IRAS/BIGMAP mosaics that preceded them, thus enabling more reliable photometry at higher Galactic latitude. Because of their improved performance at high latitude, they also extend nearly 3 times farther in Galactic latitude.

The mosaicing was done by Gaylin Laughlin and Rick Ebert at the Infrared Processing and Analysis Center (IPAC) in Pasadena. For a particular mosaic, each subimage was re-projected with respect to a common mosaic "center" and then combined together. Overlapping pixels were averaged together in the combined mosaic. The resulting mosaic images have internally consistent astrometry with little evidence of the mosaicing boundaries (see **Figure 1.2**).

We have evaluated the mosaic images in terms of residual artifacts as well as the actual emission morphology. This has involved spatial filtering to bring out the fine-scale structure in the diffuse FIR emission (cf. Waller and Boulanger 1993). We find the following major artifacts...

- 1.) Data are missing in the plate-90 mosaics in a wedge beginning at $(\ell, b) = (86^\circ, 1^\circ)$ and extending to $(78^\circ \pm 2^\circ, -28^\circ)$, and in the plate-270 mosaics in a more ragged wedge beginning at $(266^\circ, 6^\circ)$ and extending to $(257^\circ \pm 2^\circ, 29^\circ)$. These parts of the sky were never mapped during the 3 confirming surveys which IRAS made (cf. Wheelock *et al.* 1994).
- 2.) Incorrectly subtracted zodiacal emission component (see **Figure 1.3**). This problem is also described in Wheelock *et al.* (1994). From month to month, the same region in the sky contains a different distribution of interplanetary dust and corresponding zodiacal emission. Therefore, a single zodiacal emission model cannot reproduce that which IRAS detected during its 10-month survey. The largest deviations are apparent in the frames containing the Galactic center and anticenter — where the Ecliptic plane intersects the Galactic plane at an angle of approximately 55° . The 12 and 25 μm bandpasses are most obviously affected, while the 100 μm is least affected (see **Figure 1.2**).
- 3.) A discontinuity in the surface brightness is evident in the plate-045 mosaics at about 45° longitude. It is especially prominent at around $+7^\circ$ latitude, where a 30% jump is evident. Spatial filtering shows the discontinuity extending towards higher Galactic latitude and lower longitude. Another discontinuity of smaller amplitude is present at

negative latitude. It originates near the first discontinuity close to the Galactic plane, again extending towards lower longitude but at a smaller angle wrt the plane. Spatial filtering also reveals a discontinuity in the plate-225 mosaics at $(223^\circ, -16^\circ)$ extending to lower longitudes and more negative latitudes. The same features are present in mosaics made using the *SkyView* interface, indicating that the discontinuities derive from the input ISSA images rather than the particular mosaicing software.

Further information on saturated pixels and hysteresis effects from bright sources, trailing features from solar system debris, mosaicing suitability, as well as the overall photometry of the ISSA images is discussed in the Introduction to Wheelock *et al.* (1994).

The exabyte datatape was written using a Sun/Unix workstation and the "tar" utility. The NSSDC also received a listing of the tape's contents. Each image is formatted as a FITS file. The numbers 000, 045, 135, 180, 225, 270, and 315 refer to the longitudes of the image centers. The letters b1, b2, b3, and b4 respectively refer to the 12, 25, 60, and 100 μm bandpasses.

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FIGURES: MOSAICS OF FAR-INFRARED EMISSION IN THE MILKY WAY

Figure 1.1. Gnomonic (tangent plane) projection for each mosaic. Galactic longitude increases from right to left over an interval of 60° . The Galactic plane runs through the middle of the mosaic. Grid lines of constant Galactic longitude and latitude are separated by 10° . In this projection, the lines of constant longitude are straight and mutually parallel, while the lines of constant latitude bow in towards the image center.

Figure 1.2. The following 8 mosaics are logarithmically-scaled representations of the 100 μm emission in the Milky Way. The mosaics were generated from digital versions of the IRAS Sky Survey Atlas (ISSA). Each mosaic is a gnomonic (tangent plane) projection in Galactic coordinates with approximate dimensions of $60^\circ \times 60^\circ$ in Galactic longitude and latitude.

(a.) Mosaic of the inner Galaxy centered on the Galactic center ($[\ell, b] = [0.0, 0.0]$). Many intense star-forming regions (HII regions) highlight the Galactic plane, including IC 4628 at $(G344 + 2)$, NGC 6357 at $(G353 + 1)$, the Lagoon nebula — M8 at $(G6 - 1)$, the Trifid nebula — M20 at $(G7 + 0)$, the Omega nebula — M17 at $(G15 - 1)$, and the Eagle nebula — M16 at $(G17 + 1)$. Near the left and right edges are many sources

belonging to the molecular ring at ($R(\text{gal}) \approx 4\text{--}5$ kpc.) Away from the Galactic plane at positive Galactic latitude, FIR emission from the Ophiucus star-forming cloud blends into the more diffuse "cirrus" emission that pervades the image. At negative latitude, the "cometary cloud" R Corona in Australis is barely visible above the diffuse emission.

(b.) Mosaic centered at ($\ell = 45^\circ$). Prominent star-forming regions in the Galactic plane include an multitude of sources in the molecular ring (near the right edge, NGC 6823 at ($G59 + 0$), and the beginnings of the Cygnus complex at ($G78 + 2$).

(c.) Mosaic centered at ($\ell = 90^\circ$). Its FIR emission is dominated by the Cygnus star-forming region centered at ($G78 + 2$). To the left of the "S" feature in Cygnus is the Pelican nebula — IC 5067-70 at ($G84 + 0$), the North America nebula — NGC 7000 at ($G86 - 1$), and IC 1396 at ($G99 + 4$) which seems to form part of a giant shell. Near the left edge is NGC 7822 at ($G118 + 6$) which also shows a shell-like morphology.

(d.) Mosaic centered at ($\ell = 135^\circ$). Near-plane features include shell-like NGC 7822 at ($G118 + 6$), IC 59, IC 63 and γ Cas at ($G124 - 2$), IC 1805 at ($G135 + 1$), and IC 1848 at ($G137 + 1$). At negative latitude, M31 shows prominently at ($G121 - 21$), while the California nebula — NGC 1499 at ($G160 - 12$) and IC438 at ($G160 - 18$) dominate the lower left of the mosaic.

(e.) Mosaic centered at ($\ell = 180^\circ$). Near-plane features include NGC 1579 at ($G165 - 9$), NGC 1907 at ($G173 + 0$), IC 443 at ($G189 + 3$), NGC 2174 at ($G190 + 1$). At negative latitude, the California nebula — NGC 1499 at ($G160 - 12$), IC 438 at ($G160 - 18$), and the Pleiades — M45 at ($167 - 23$) appear in the lower right, while the large shell S264 — λ Ori at ($G195 - 12$), the Cone Nebula — NGC 2259 at ($G203 + 2$), and the Rosette nebula — NGC 2237-39/2246 at ($G206 - 2$) dominate the lower left.

(f.) Mosaic centered at ($\ell = 225^\circ$). It's FIR emission is dominated by the Orion star-forming region at negative latitude, including the Horsehead nebula at ($G206 - 16$) and the Orion nebula at ($G209 - 19$). Also featured is the Cone nebula, the Rosette nebula, Mon R2 — NGC 2170 at ($G214 - 12$) and NGC 2327 at ($G224 - 2$).

(g.) Mosaic centered at ($\ell = 270^\circ$). It's FIR emission is dominated by the Eta Carina star-forming region — NGC 3324 at ($G287 - 1$).

(h.) Mosaic centered at ($\ell = 315^\circ$). Near-plane features include IC 2944 at ($G294 - 1$) and many other star-forming regions in the molecular ring (towards the left edge). The Coal Sack at ($G303 - 1$) is not prominent despite its large dust content.

Figure 1.3. Mosaic of $25\ \mu\text{m}$ emission from the inner Galaxy (scaled to equalize the emission histogram). The mosaic is centered on the Galactic center and has approximate dimensions of $60^\circ \times 60^\circ$ in Galactic longitude and latitude. The gnomonic (tangent plane) projection causes the superposed grid lines of constant latitude to bow in towards the image center. Imperfect estimation and subtraction of the bright zodiacal emission at $25\ \mu\text{m}$ has led to residual bands running parallel to the Ecliptic plane. This problem virtually disappears at $100\ \mu\text{m}$ (see Figure 1.2).

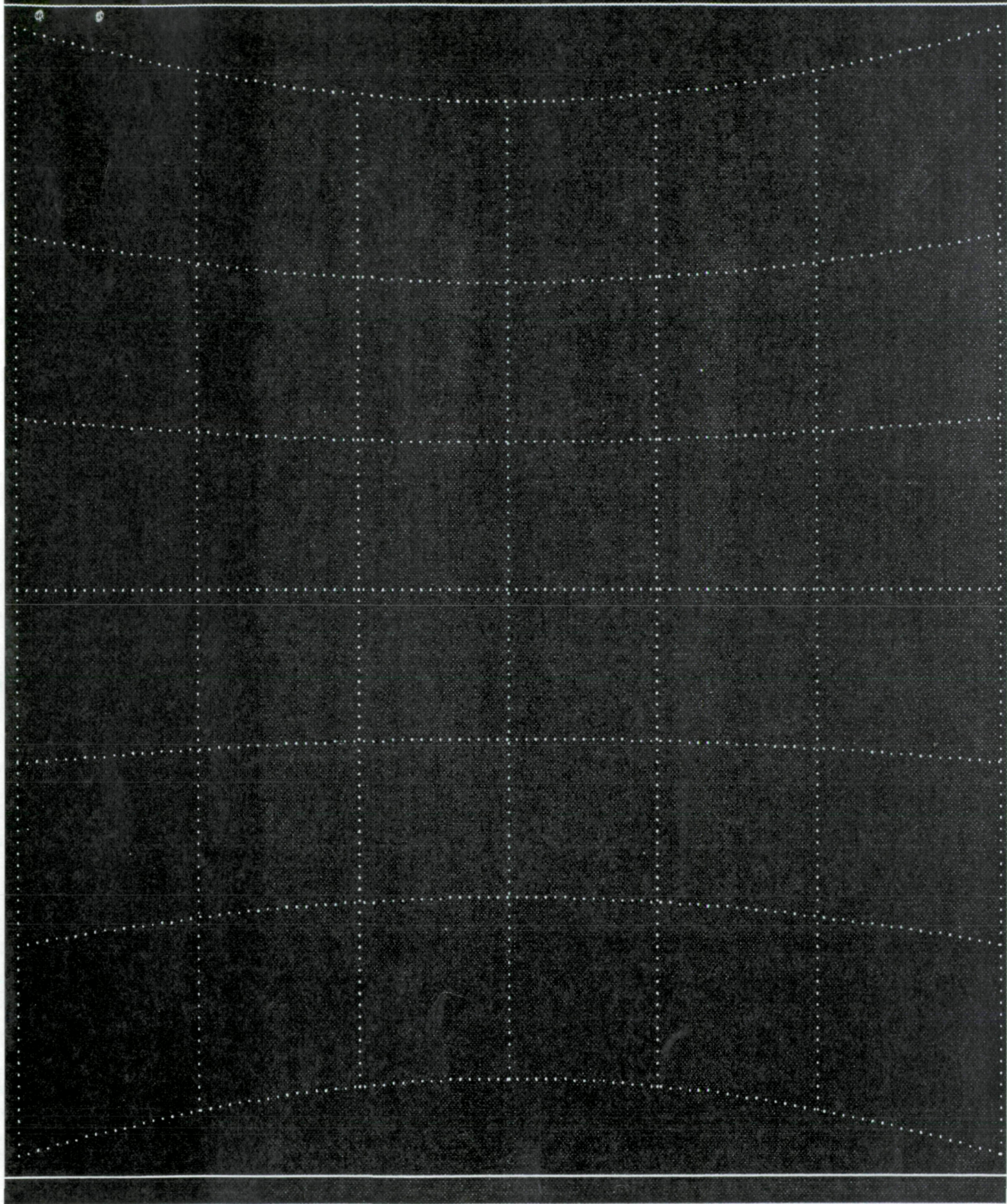


Fig. 1.1

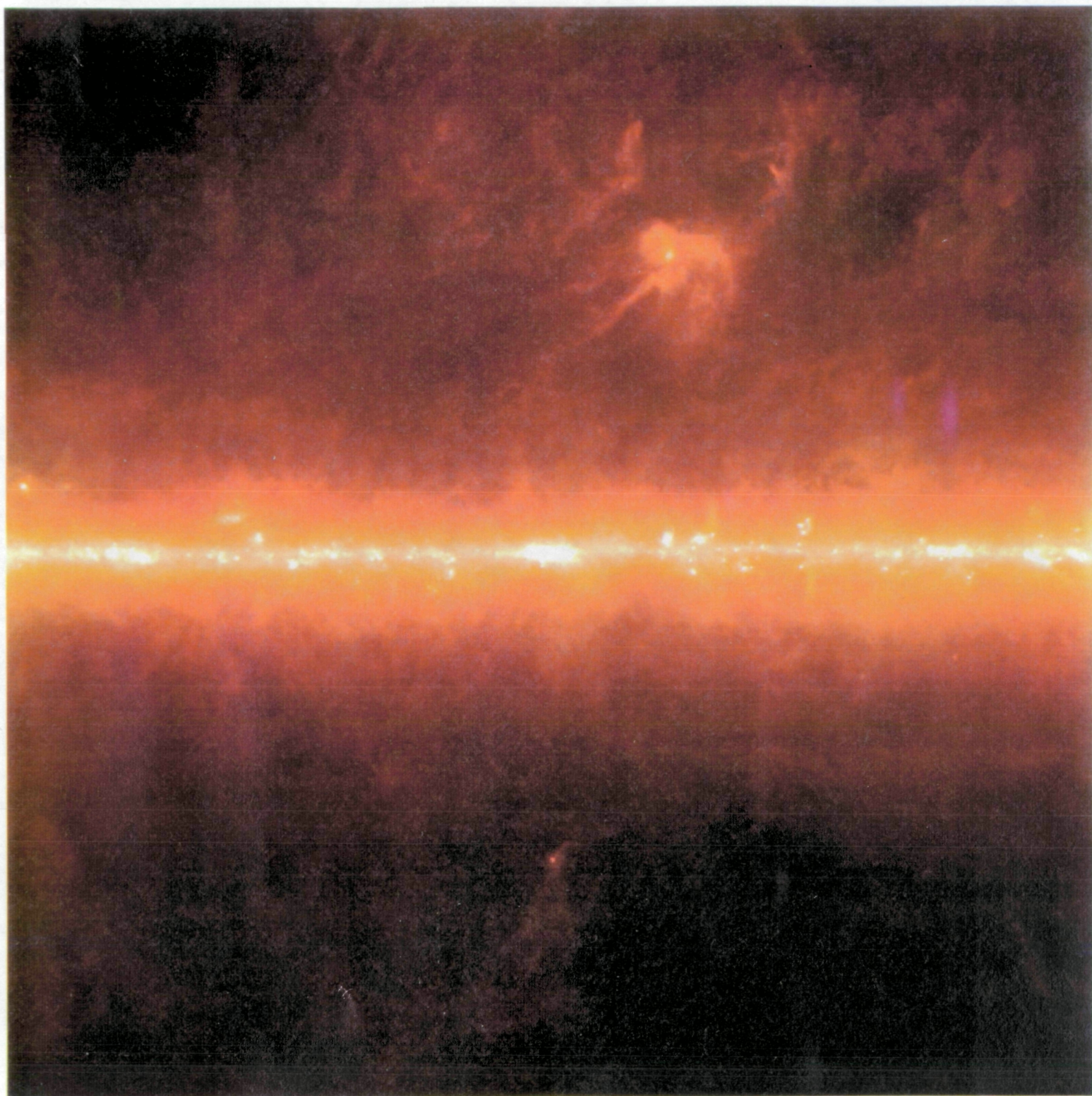


Fig. 1.2 (a)

$$l = 0^\circ$$

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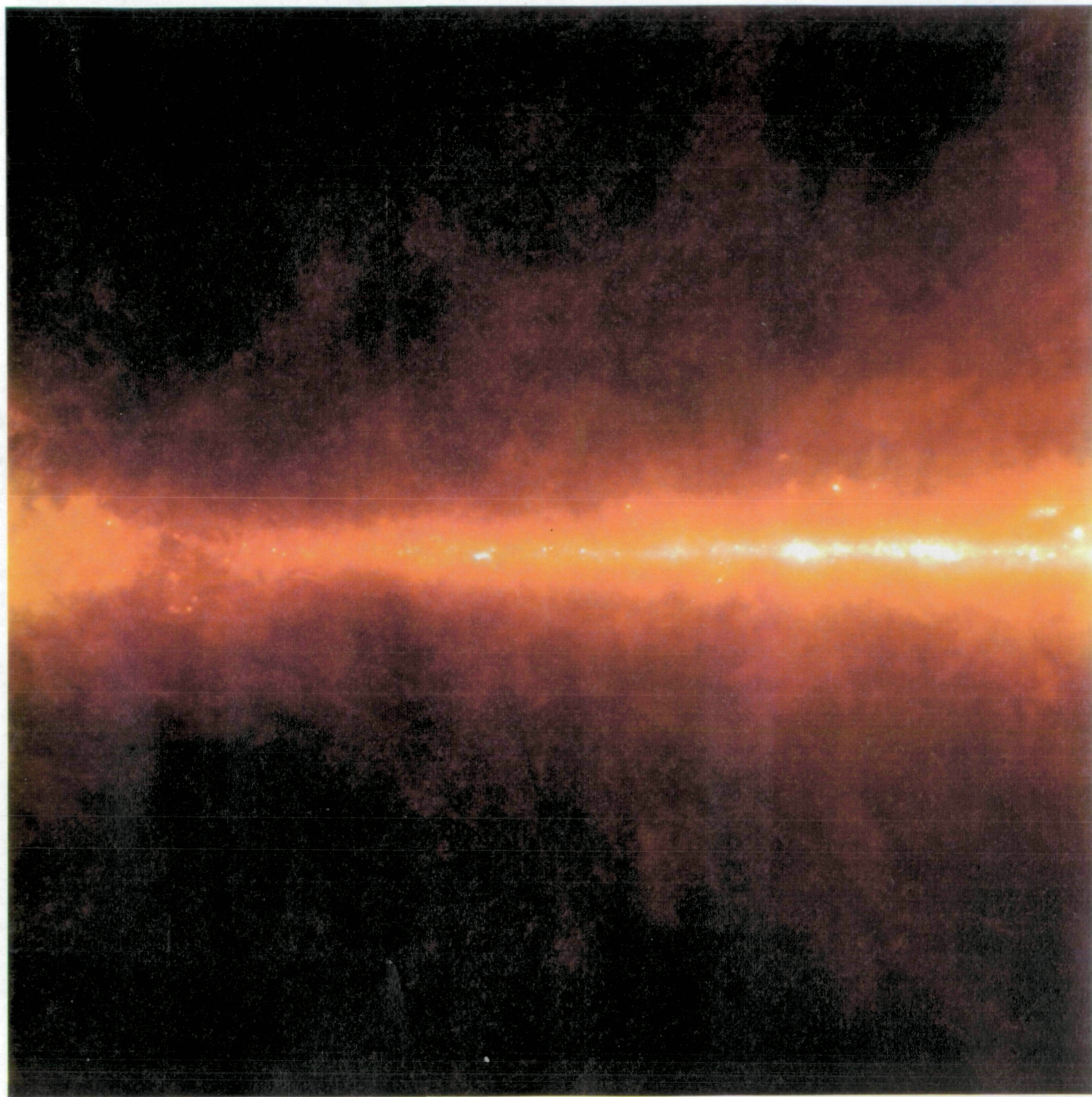


Fig. 1.2(b)

$\beta = 45^\circ$

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Fig. 1.2 (c)

$$l = 90^\circ$$

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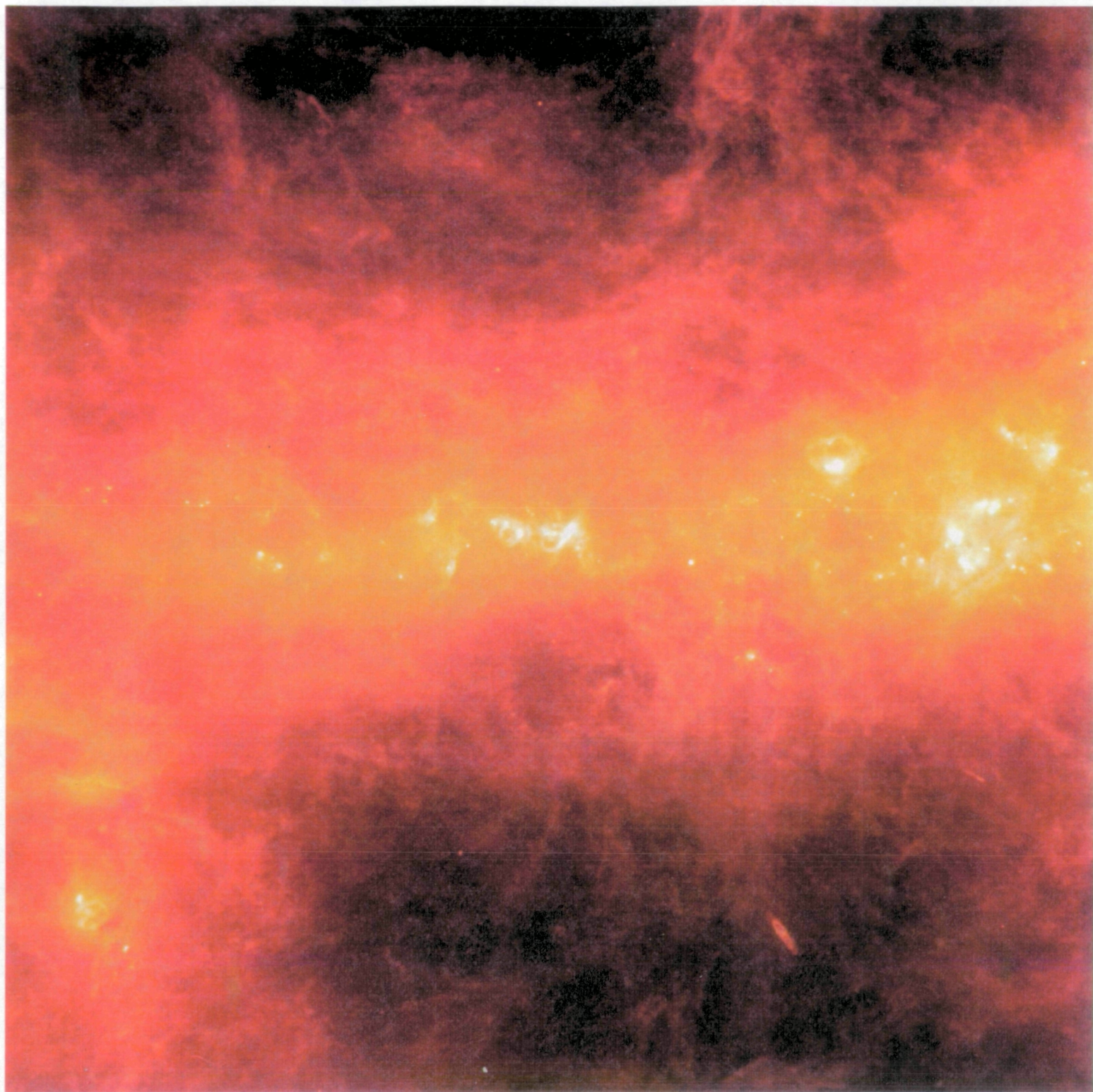


Fig. 1.2(d)

$\ell = 135^\circ$

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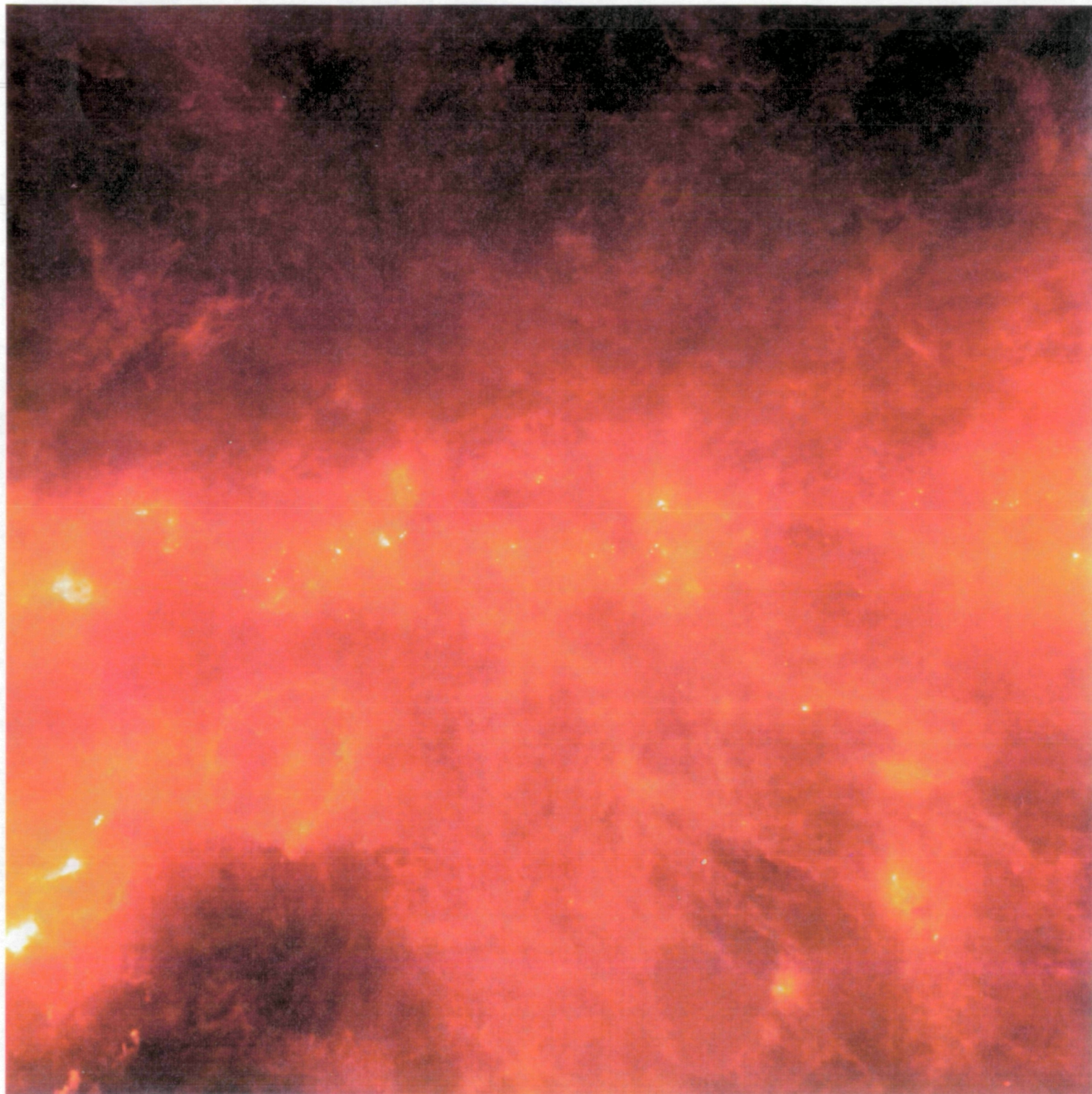
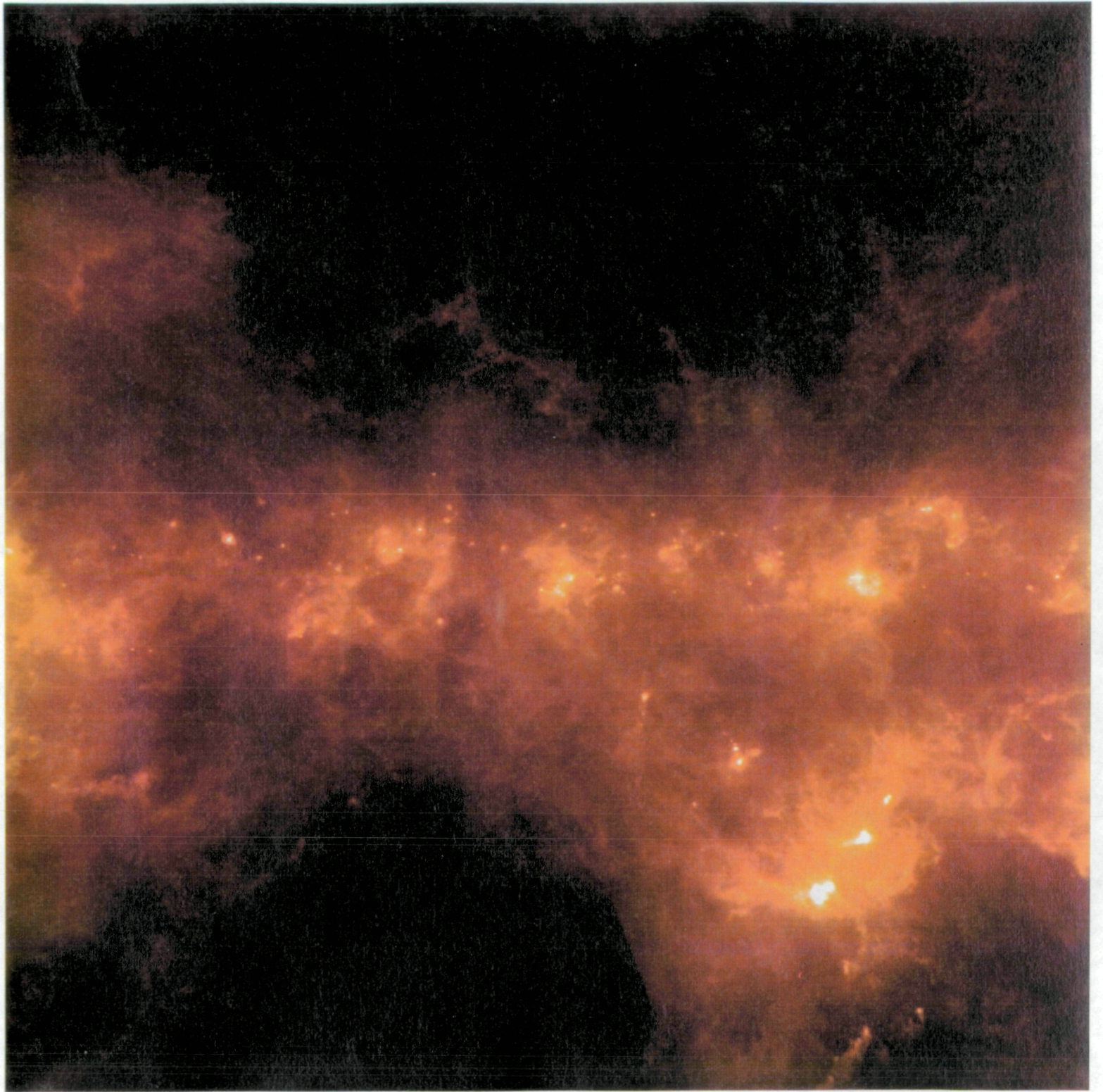


Fig. 1.2(c)

$\phi = 180^\circ$

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Fig. 1.2 (f)
 $\ell = 225^\circ$

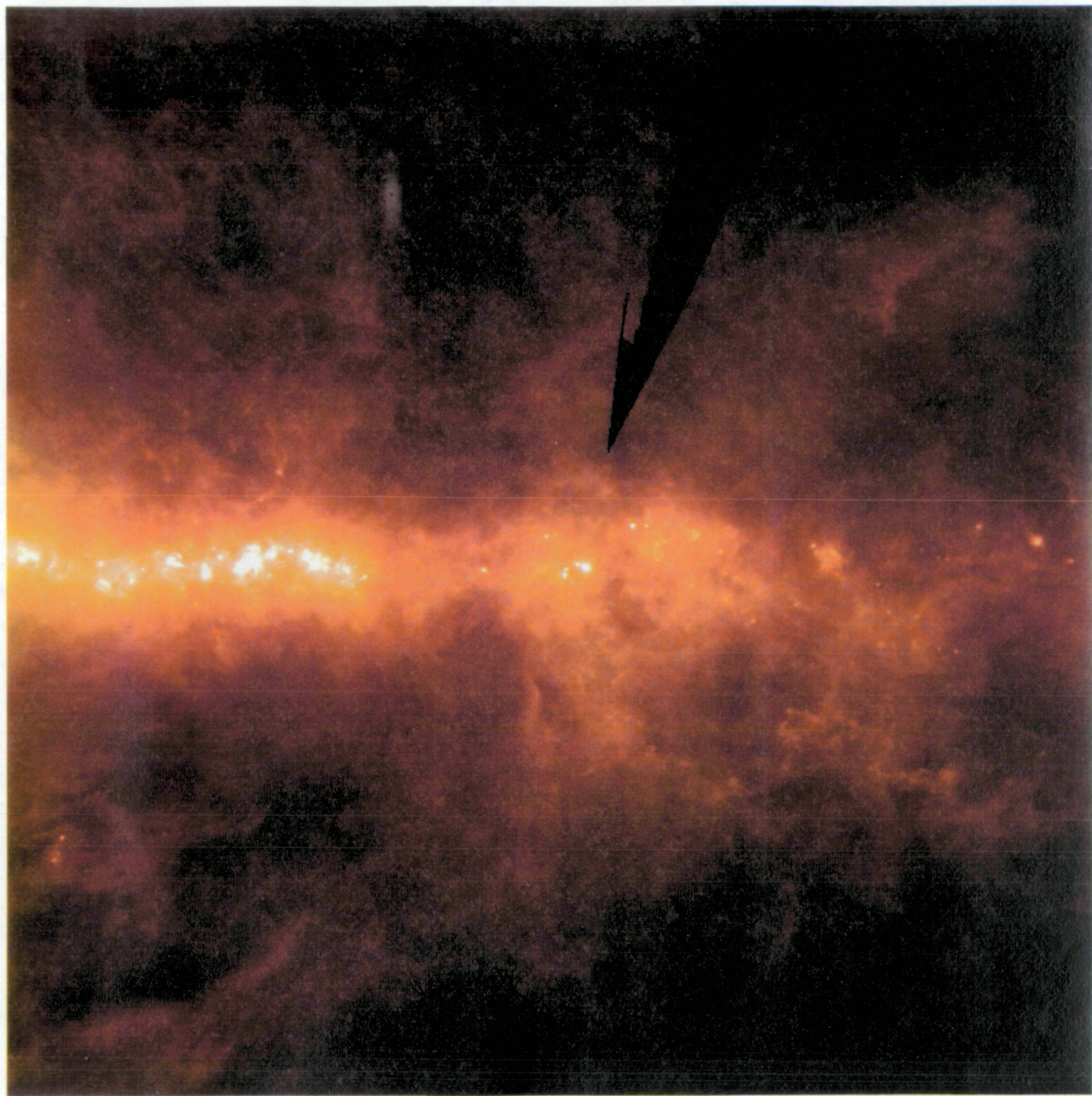
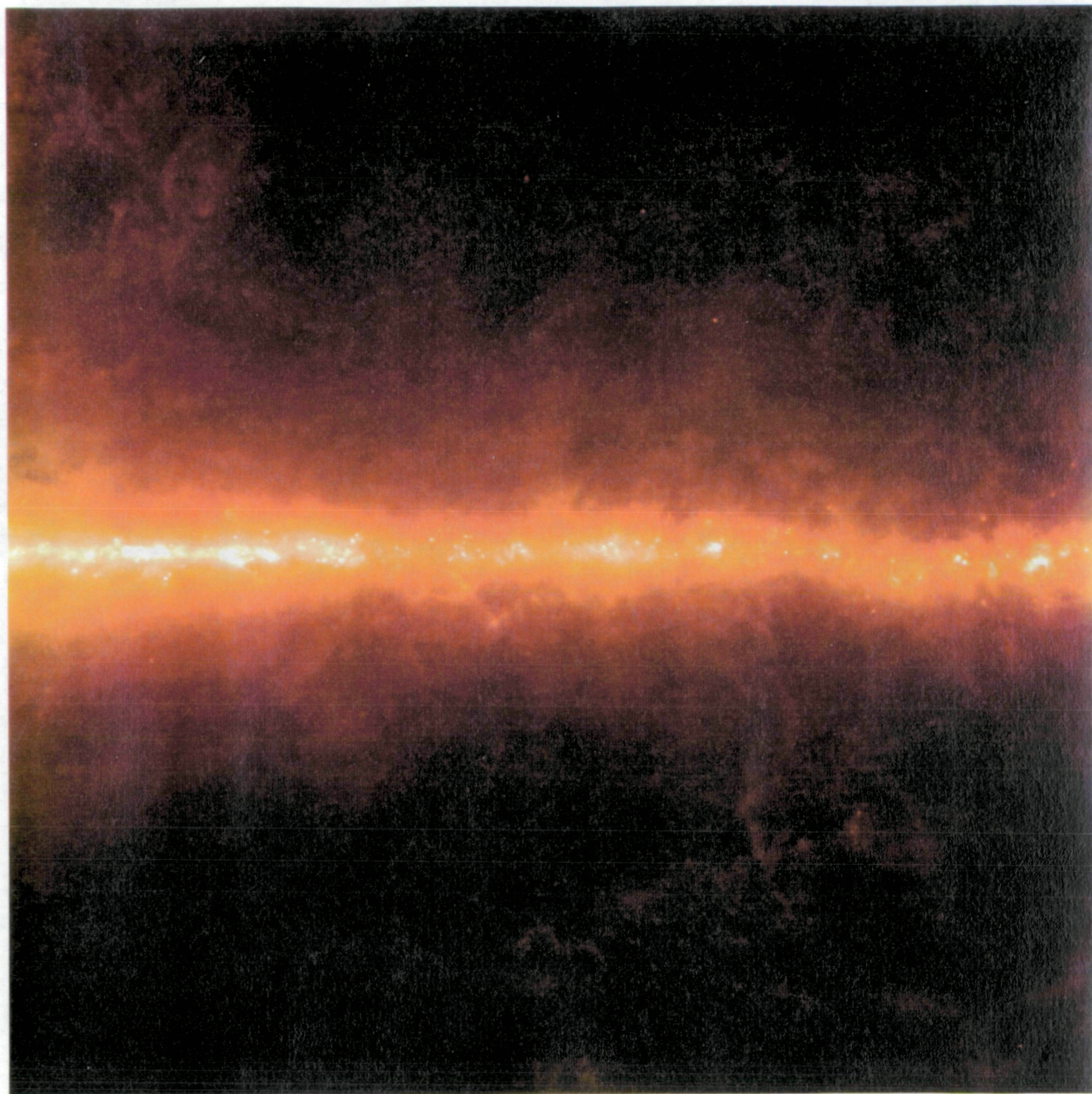


Fig. 1.2(g)
 $\beta = 270^\circ$

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Fig. 1.2(h)
 $\lambda = 315^\circ$

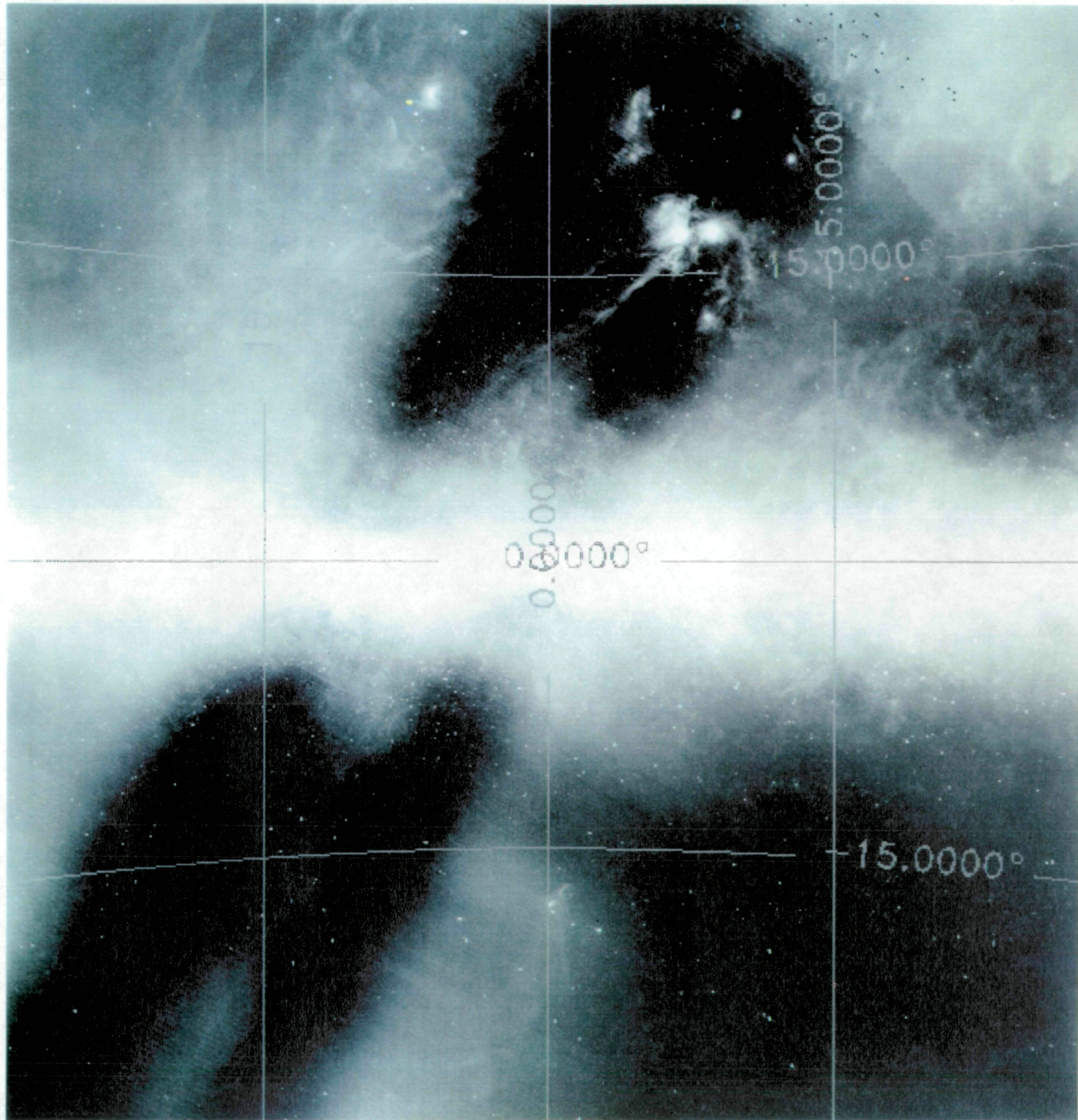


Fig. 1.3

$$l = 0^\circ$$

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2. Acquisition of Associated Data at Other Wavelengths

A workstation was needed that had the required disk space. Considering the volume of data involved in this project, 100-200 MBytes of disk are required for original and processed data. A suitable workstation was located, which uses the Ultrix operating system. Since this is a UNIX-based operating system, data compression is possible and is straightforward, with compression factors of 2-5. The compression allowed us to save valuable disk space.

Acquired datasets were transferred to the project workstation and compressed. These datasets include the $62^\circ \times 22^\circ$ mosaics of IRAS/BIGMAP images and the CII 158 μm line map by Nakagawa (1992). A copy of the Bell Labs 21-cm HI Survey (Stark 1992) was obtained, but, because the spatial resolution (i.e. 2° FWHM) is poorer than that of Heiles & Habing (1974, i.e. 0.6° FWHM), these data were deemed extraneous.

Additional data acquisitions were maps of the 2300 MHz continuum, 1420 MHz continuum, HI 21-cm line, and CO (1-0) 2.6-mm line. The high-resolution ($20'$) 2300 MHz continuum data were obtained in FITS format by FTP from Dr. Justin Jonas at Rhodes University in Grahamstown, South Africa. The 1420 MHz continuum data (Reich 1978) were available in FITS format from the NASA/GSFC COBE Cluster. The HI 21-cm line data were obtained in tabular ASCII form from Dr. Bill Reach. The CO(1-0) line data (Dame 1987) were available in FITS format from Dr. Tom Dame at the Center for Astrophysics in Cambridge, Massachusetts. These data sets are listed in Table 1.

The processing consists of initial processing for some of the data followed by application of a median-normalizing spatial filter (see sections 3 & 4).

- a.) Initial Processing: An error in the FITS headers for the IRAS/BIGMAP mosaics produced incorrect coordinate grids. The headers stated that the projection was gnomonic, but overlaps of adjacent maps and discussions with Dr. Walter Rice (formerly with IPAC) verified that the projection was NOT gnomonic but linear.

An error in the FITS header for the CII 158-micron data also resulted in an incorrect coordinate grid. Comparison of the FITS map with that in Nakagawa (1992) and a discussion with Dr. Nakagawa remedied the error.

The 1420 MHz continuum data, originally in 4 separate maps, were concatenated.

The HI data came from 4 different datasets (Heiles & Habing 1974, Weaver & Williams 1973, Cleary et al. 1979, Kerr et al. 1986) and were acquired by Dr. Reach. Dr. Reach integrated the data over velocity and created a table of integrated brightness temperatures along with the Galactic coordinates. Dr. Wall used the HI data table to grid the data at 0.5° intervals in both Galactic longitude and Galactic latitude. For positions with no data (i.e. "holes"), interpolation with $1/r^2$ weighting was performed within 3.5° square patches centered on each hole. This interpolation scheme minimized flaws in the HI line map.

- b.) Filtering: In making comparisons between different tracers of the interstellar medium (see Section 6), we first concentrated on the latitude range $b = -11^\circ$ to $+11^\circ$, where we spatially filtered all the aforementioned maps to bring out their fine-scale

structure. The preferred mode of spatially filtering consists of median-smoothing by 15° in Galactic longitude (no smoothing in latitude) and then dividing the original (unsmoothed) map by the smoothed map (see next section). This median-normalizing form of spatial filtering results in maps of fine-scale structure that de-emphasize the Galactic Plane. It was necessary, where possible, to append "extra" data to the left and right edges of the maps in order to avoid edge effects. For example, in an all-sky map running from $\ell = +180^\circ$ to -180° , the left and right 15° strips were copied and placed on the opposite sides so that the map now extended from $\ell = +195^\circ$ to -195° . After the filtering, the "extra" edges were discarded.

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Table 1: Acquired Data Sets
(In Addition to $60^\circ \times 60^\circ$ IRAS/ISSA Mosaics)

Data Set	Sky Coverage	Pixels	Size (kBytes)
IRAS/BIGMAP	6 mosaics covering $\ell = +180^\circ$ to -180° and $b = -11^\circ$ to $+11^\circ$	$3'$ (1240×440)	6×2152
$12\mu\text{m}$	"	"	"
$25\mu\text{m}$	"	"	"
$60\mu\text{m}$	"	"	"
$100\mu\text{m}$	"	"	"
CII $158\mu\text{m}$	$\ell = 25^\circ$ to -11° $b = -6^\circ$ to $+6^\circ$	$3'$ (761×201)	320
1420 MHz	Northern Sky	$15'$ (1441×721)	320
2300 MHz	Southern Sky	$20'$ (1080×541)	2296
HI 21-cm	All Sky (except Galactic Center)	$30'$ (721×361)	1032
CO (1 - 0)	$\ell = +180^\circ$ to -180° $b = -25^\circ$ to $+25^\circ$	$30'$ (721×361)	160

3. Spatially Filtered Maps of the FIR Fine-Scale Structure

To facilitate the spatial filtering, we began with mosaics which have rectangular projections. These were obtained using the “SkyView” advanced interface on the World Wide Web (URL = <http://skview.gsfc.nasa.gov/skyview.html>). Each image has dimensions of $60^\circ \times 60^\circ$ in Galactic longitude and latitude with a pixel size of $0.05^\circ \times 0.05^\circ$. **Figure 3.1** shows the $100\mu\text{m}$ mosaic of the inner Galaxy with a rectangular grid of Galactic longitudes and latitudes superposed on the grey-scale image.

The rectangular-projected mosaics were then median smoothed with the aim of extracting the ambient, smoothly-varying emission in the Galaxy. We used a median-smoothing window with dimensions of $(15^\circ \times 0.05^\circ)$ in Galactic longitude and latitude. In this way, the processing smooths over most of the longitudinal structure in the image while retaining the strong emission gradient in latitude towards the Galactic midplane. **Figure 3.2** shows the resulting median-smoothed image for the $100\mu\text{m}$ mosaic of the inner Galaxy.

The most common form of median filtering is to *subtract* the median-smoothed image from the original image. An example of the resulting residual emission is shown in **Figure 3.3**, where the median-smoothed image in **Figure 3.2** has been subtracted from the original image in **Figure 3.1**. This sort of spatial filtering yields absolute emission residuals and deficits in units of MJy/Sr. It tends to highlight the near-plane deviations from a uniform disk of emitting dust as viewed from within the disk. The greatest absolute deviations occur near the plane, because the greatest integrated emission is located there. Were this not the case, the deviations would not be related to the smoothly varying emission — being of local origin instead. Similarly processed maps of the Milky Way have led to interpretations of “worms” of dust and associated gas emanating from the Galactic plane as in scenarios of Galactic “chimneys” venting hot gas from giant HII regions and supernova remnants into the Galactic halo (Koo, Heiles, and Reach 1992). This interpretation depends critically on the specific filtering that is used, however.

Another form of median filtering is to *divide* the original image by the median-smoothed image. This sort of spatial filtering produces images of *relative* enhancements and deficits as normalized by the smoothly varying emission. As seen in the mosaics of **Figure 3.4**, the *Median Normalizing Spatial Filter* — *MNSF* eliminates all of the *cosecant b* brightening towards the Galactic midplane while highlighting the structure at all Galactic latitudes. The worm-like features evident in the images of *absolute residuals* now become parts of a larger, more complex scene. Instead of “worms” rooted in the Galactic plane, filamentary and shell-like features are evident at all latitudes. For example, in the filtered image of the inner Galaxy (**Figure 3.4a**), HII regions in the Galactic plane show clearly, the nearby clouds in Ophiucus and Corona Australis stand out in stunning contrast and detail above and below the Galactic plane, while a shell-like structure near (G310 – 24) is revealed for the first time (Boulanger and Waller 1993; Waller and Boulanger 1993).

The filamentary or froth-like fine-scale structure revealed by the MNSF processing extends all the way down to the Galactic midplane. Moreover, it scales in intensity with the smoothly varying background, independent of latitude, thus indicating that the fine-scale residual emission is co-extensive with the smooth background. If the *cosecant b* behavior of the smoothly varying background is the result of observing an edge-on disk of

emitting dust, then the fine-scale residual emission originates from dust features that are similarly distributed. *Therefore, this cirrus-like structure is not merely of local origin, but consists of both nearby and more distant features in the disk* (Waller and Boulanger 1994 [see Appendix A]).

Further support for a disk-wide distribution of fine-scale structure is obtained from a simple comparison of the unfiltered FIR emission from the inner and outer Galaxy. By assuming that the outer Galaxy emission is dominated by local features, one can examine the ratio $I(\text{outer})/I(\text{inner})$ as a function of Galactic latitude and thereby set upper limits on the proportion of emission from the inner Galaxy that is local.

Figure 3.5 presents the ratio $I(\text{outer})/I(\text{inner})$ as a function of Galactic latitude. The inner-Galaxy emission is averaged over the longitude range of -30° to 30° . The outer-Galaxy emission is averaged over 150° to 210° in longitude. At the Galactic midplane, a maximum of 1% of the emission from the inner Galaxy is local in origin. At 5° latitude, 25% to 35% is local; and at 10° latitude, 50% to 100% is local. Because the fine-scale structure in the inner Galaxy is co-extensive with the overall emission, these estimates of the local contribution also apply to the fine-scale structure.

The plot of emission anisotropy in Figure 3.5 also shows a local excess at high negative latitudes compared to the local contribution at high positive latitude. This can be attributed to portions of the Orion and Perseus star-forming regions adding disproportionately to the local contribution at negative latitude.

Although we had expected to find morphological evidence for supernova-driven "worms" or "chimneys" rooted in the Galactic plane (cf. Koo et al. 1992; Reach et al. 1993), our processing shows the FIR fine-scale structure to be more complex (e.g. less coherent and less rooted) as viewed in projection. This may be due to the varying distances and sizes of the emitting features. The observed froth of superposed filaments, voids, and shells presents a strong challenge to investigators endeavoring to characterize the morphology, volume filling, and dynamics of the multi-phased interstellar medium (cf. Waller and Boulanger 1993).

The following section presents a "reality check" on the validity of the processing used to reveal the fine-scale structure. Section 5 presents the spatial statistics of the fine-scale FIR emission, while Section 6 presents our efforts at determining the interstellar counterparts to the observed froth — an essential step towards understanding the morphological balance of phases in the ISM.

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FIGURES:

Figure 3.1. Mosaic of the $100\mu\text{m}$ emission from the inner Galaxy, with longitude increasing from right to left from 330° (-30°) to $+30^\circ$, and latitude ranging from -30° to $+30^\circ$. As shown by the superposed grid, the projection is rectangular. The emission has been logarithmically scaled to compress its high dynamic range.

Figure 3.2. Mosaic of the $100\mu\text{m}$ emission from the inner Galaxy after having been median smoothed with a window of dimension $(15^\circ \times 0.05^\circ)$. This sort of smoothing retains the strong gradient in surface brightness towards the Galactic midplane while smoothing over most variations in longitude. The emission is logarithmically scaled.

Figure 3.3. Mosaic of the $100\mu\text{m}$ emission from the inner Galaxy after having subtracted off the median-smoothed image shown in **Figure 3.2**. This sort of median filtering produces images of absolute residuals and deficits in units of MJy/Sr. The emission is logarithmically scaled.

Figure 3.4. Mosaics of the $100\mu\text{m}$ emission in the Milky Way after division by the corresponding median-smoothed image. This sort of median filtering (*Median Normalizing Spatial Filter (MNSF)*) produces images of *relative* residuals and deficits — where a value of 0 indicates a void in the fine-scale emission, 1 indicates emission at ambient levels, and higher values indicate enhancements above ambient. Each image measures $60^\circ \times 60^\circ$ in Galactic longitude and latitude. The 8 images are centered at 0° latitude with longitude centers of (a) $0^\circ = 360^\circ$, (b) 45° , (c) 90° , (d) 135° , (e) 180° , (f) 225° , (g) 270° , and (h) 315° .

Figure 3.5 Scan in Galactic latitude of the anisotropy in $100\mu\text{m}$ emission from the outer and inner Galaxy, $I(\text{outer})/I(\text{inner})$. The emission from each direction is an average over 60° in Galactic longitude. The range in latitude is from -11° to 11° , where the midplane is at $\text{pix} = 221$. A value of unity indicates equal emission from both sextants. If the outer Galaxy emission is dominated by local features, values significantly less than unity indicate the significant presence of non-local features contributing to the emission in the inner Galaxy.

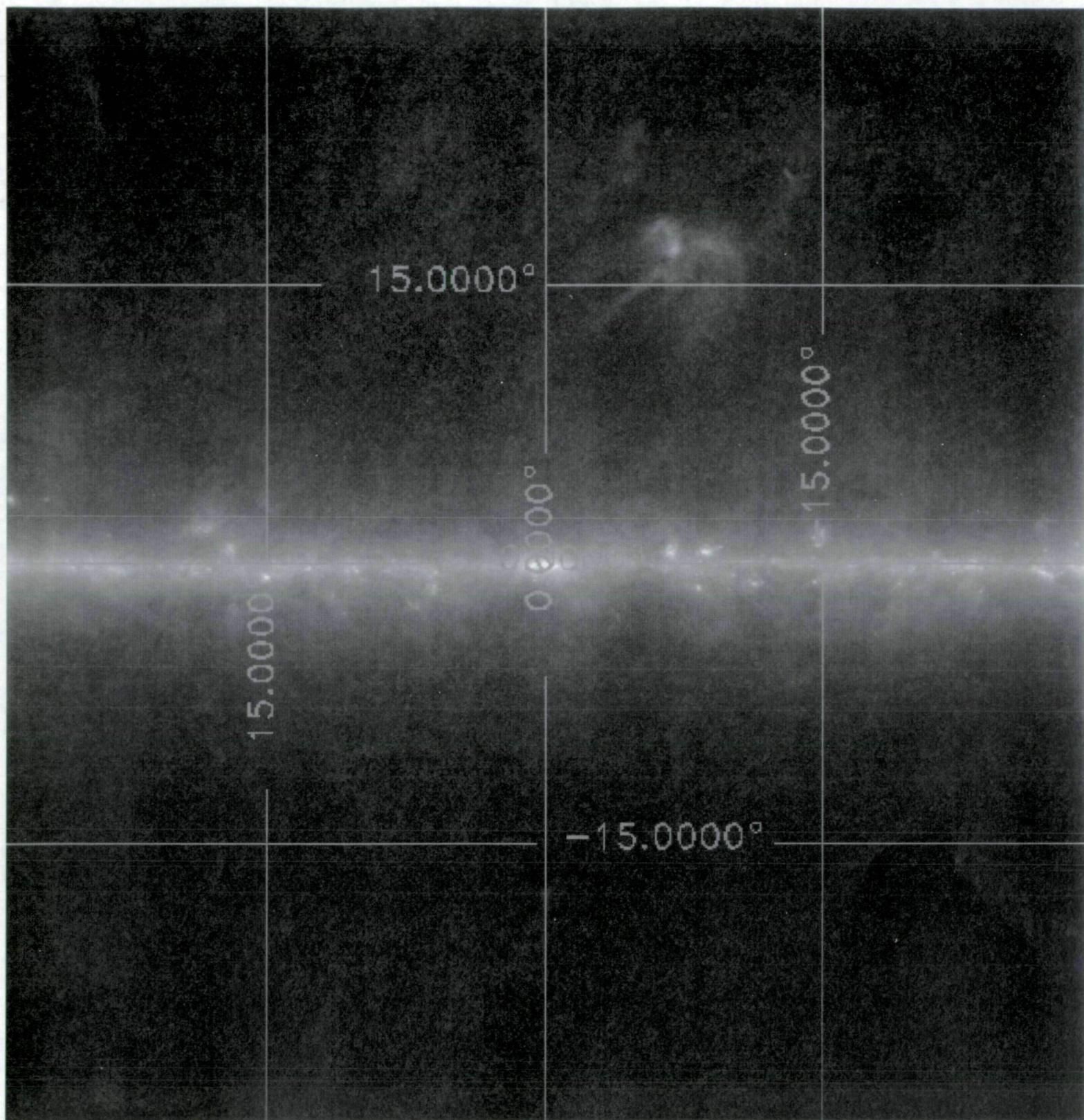


Fig. 3.1

$$l = 0^\circ$$

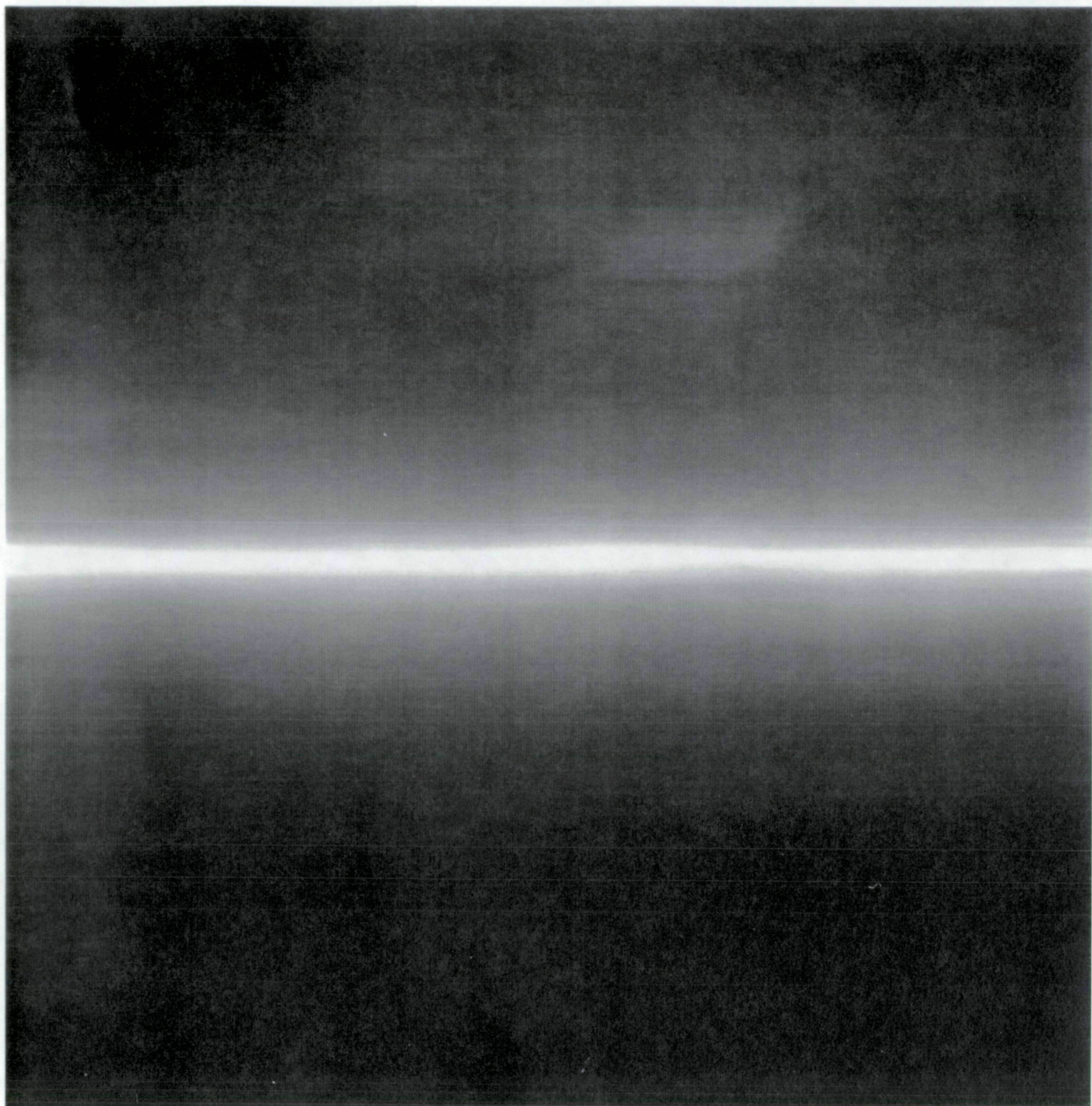


Fig. 3.2

$$l = 0^\circ$$

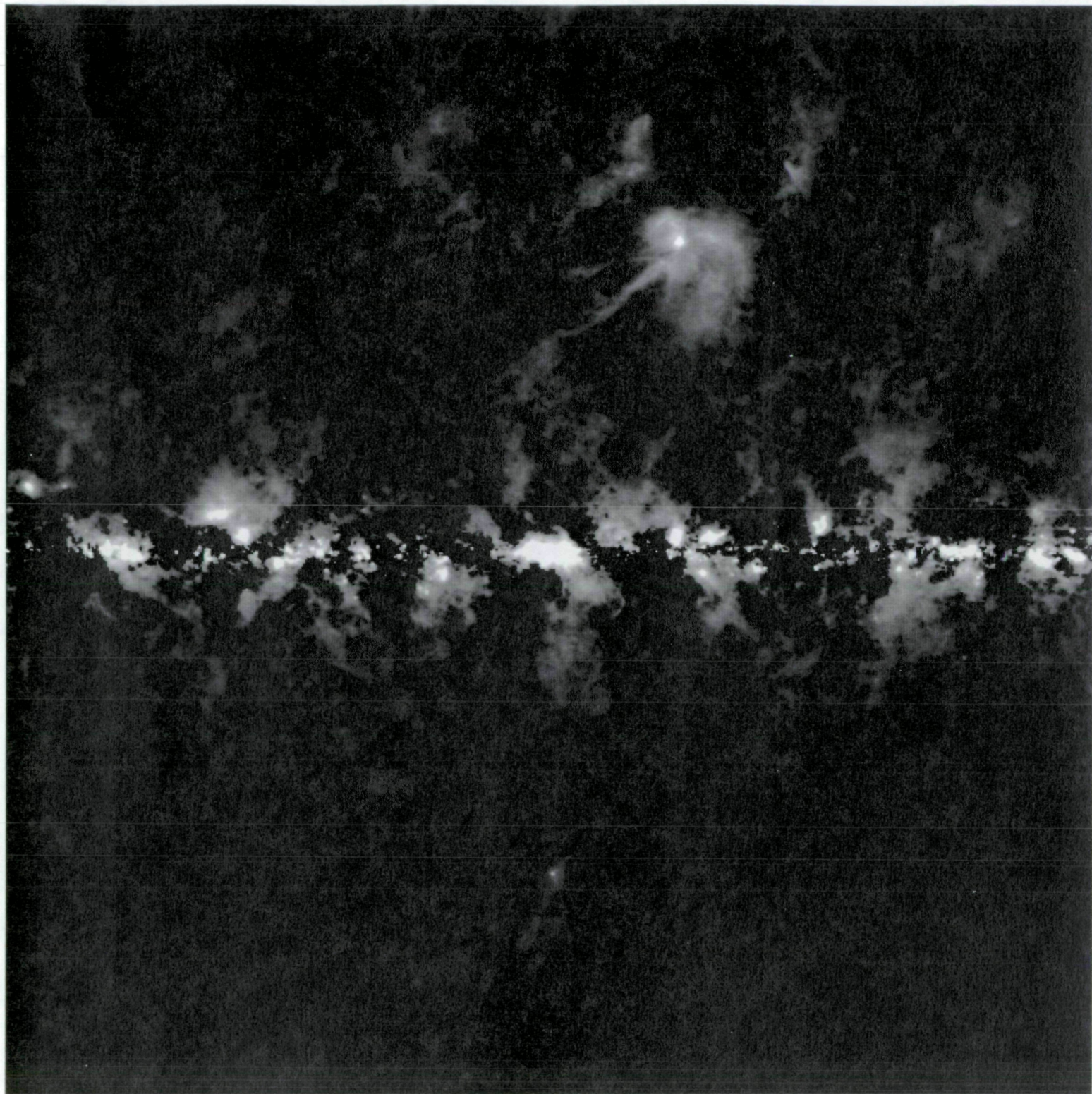


Fig. 3.3

$$l = 0^\circ$$

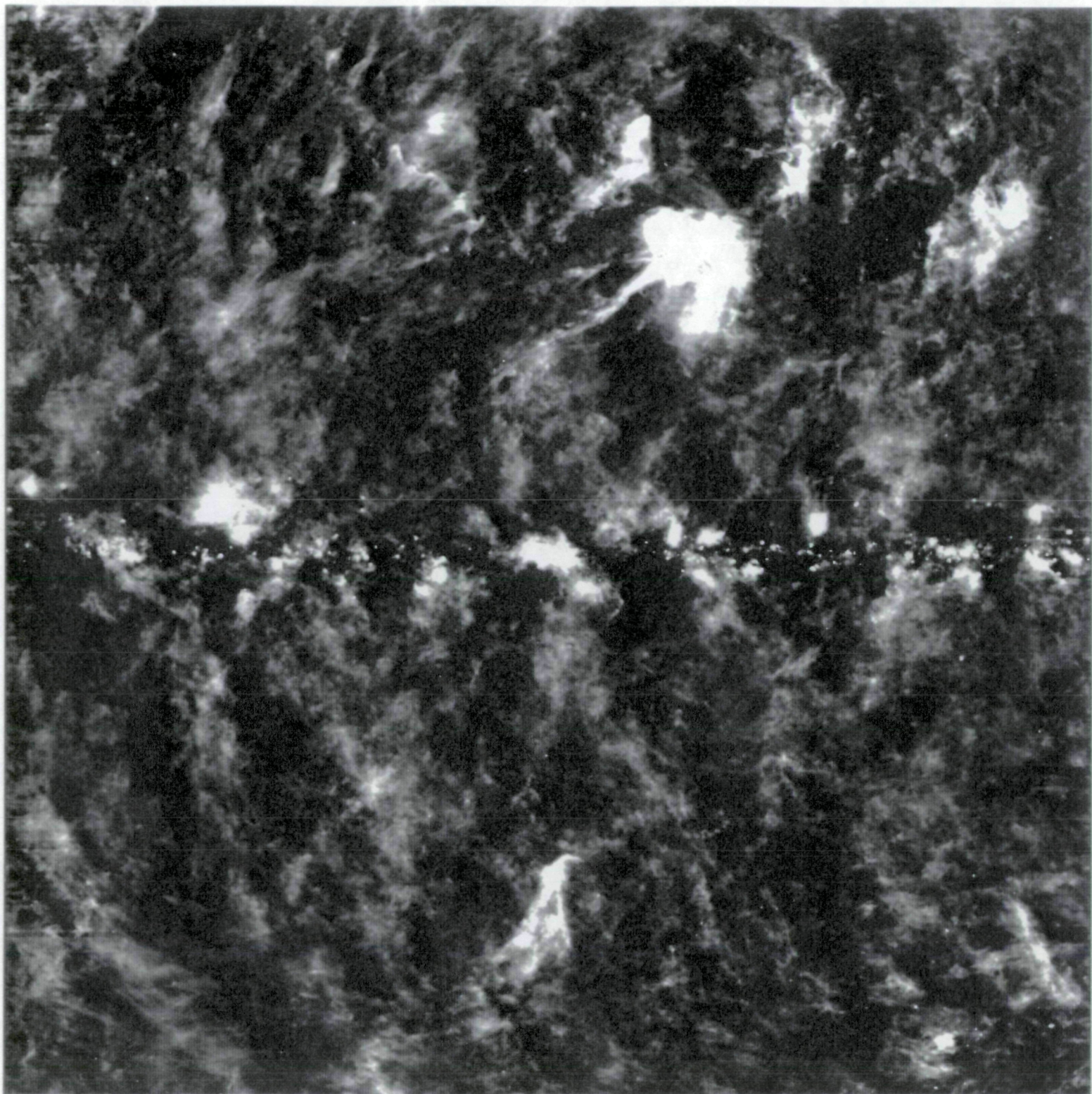


Fig. 3.4a
 $l = 0^\circ$

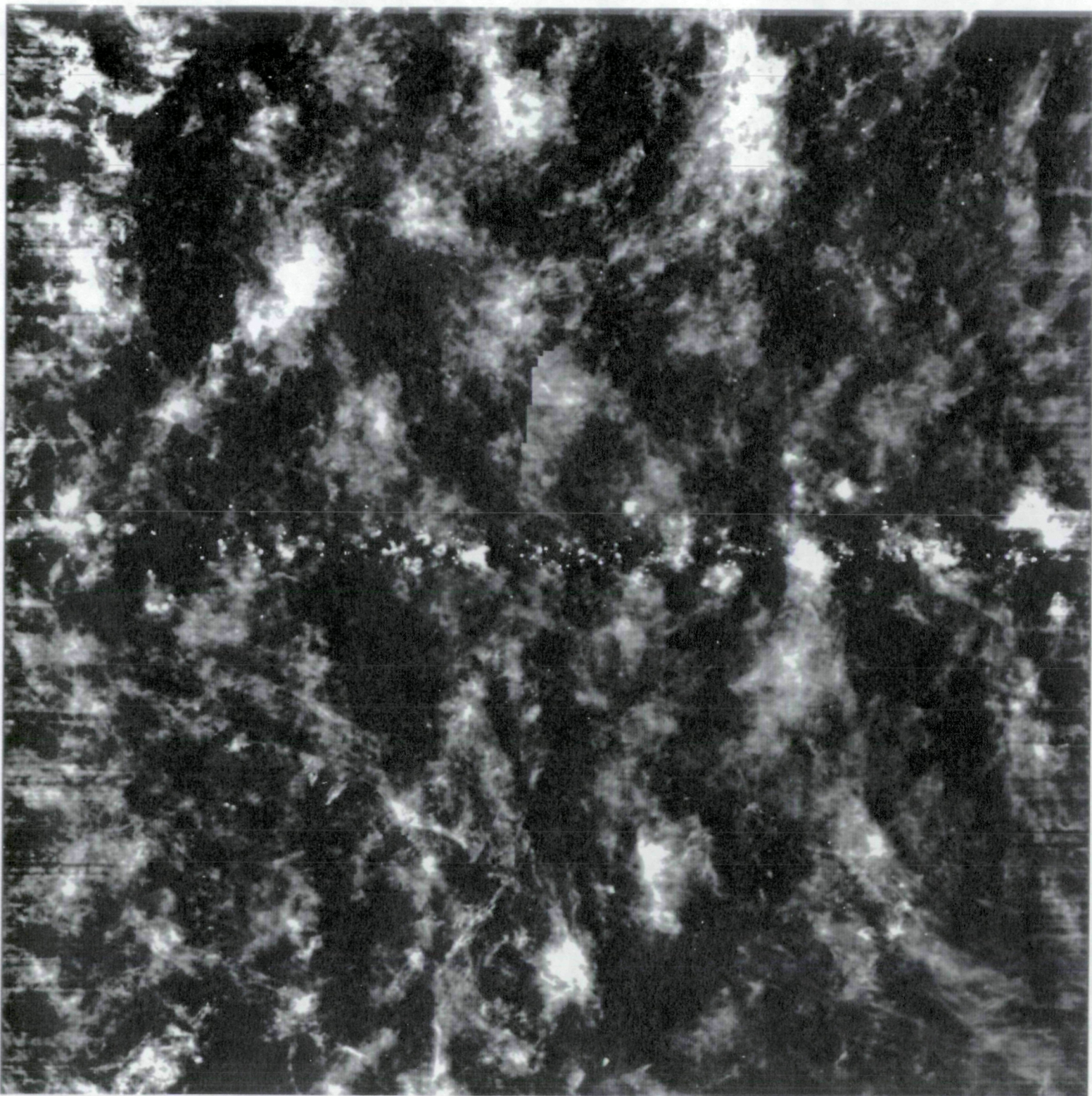


Fig. 3.46

$$\lambda = 45^\circ$$

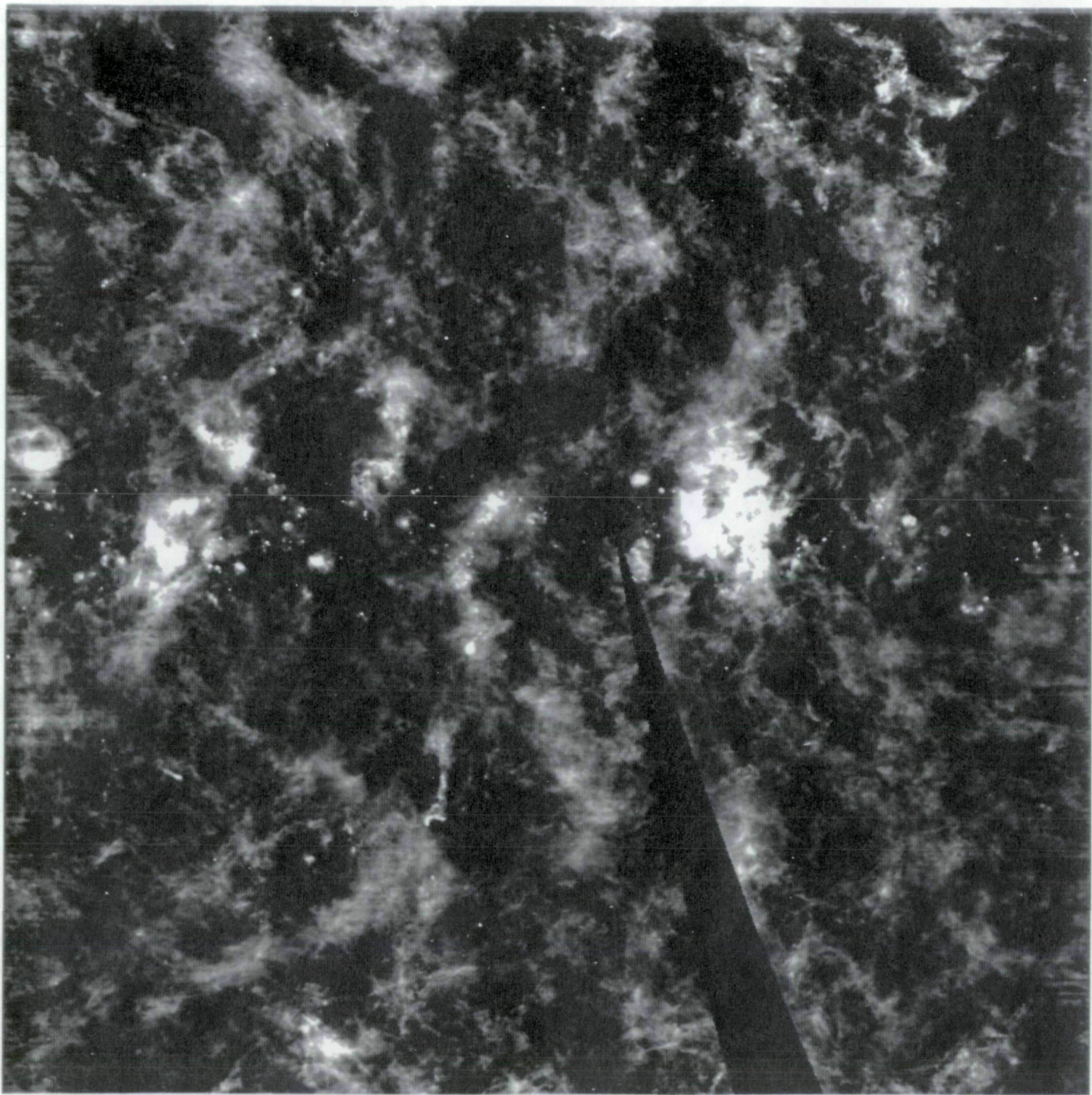


Fig. 3.4C
 $\lambda = 90^\circ$

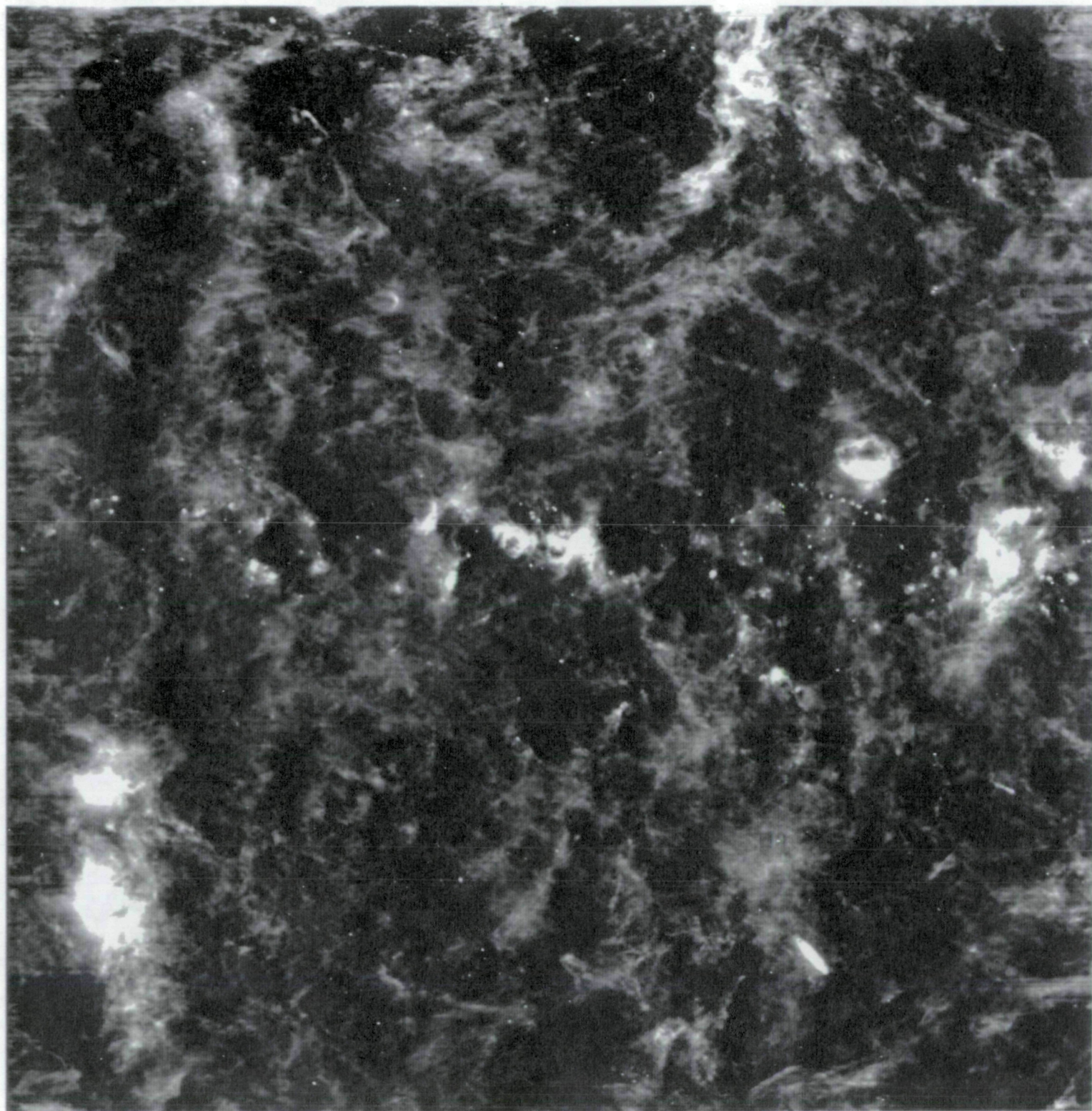


Fig. 3.4d
 $\lambda = 135^\circ$

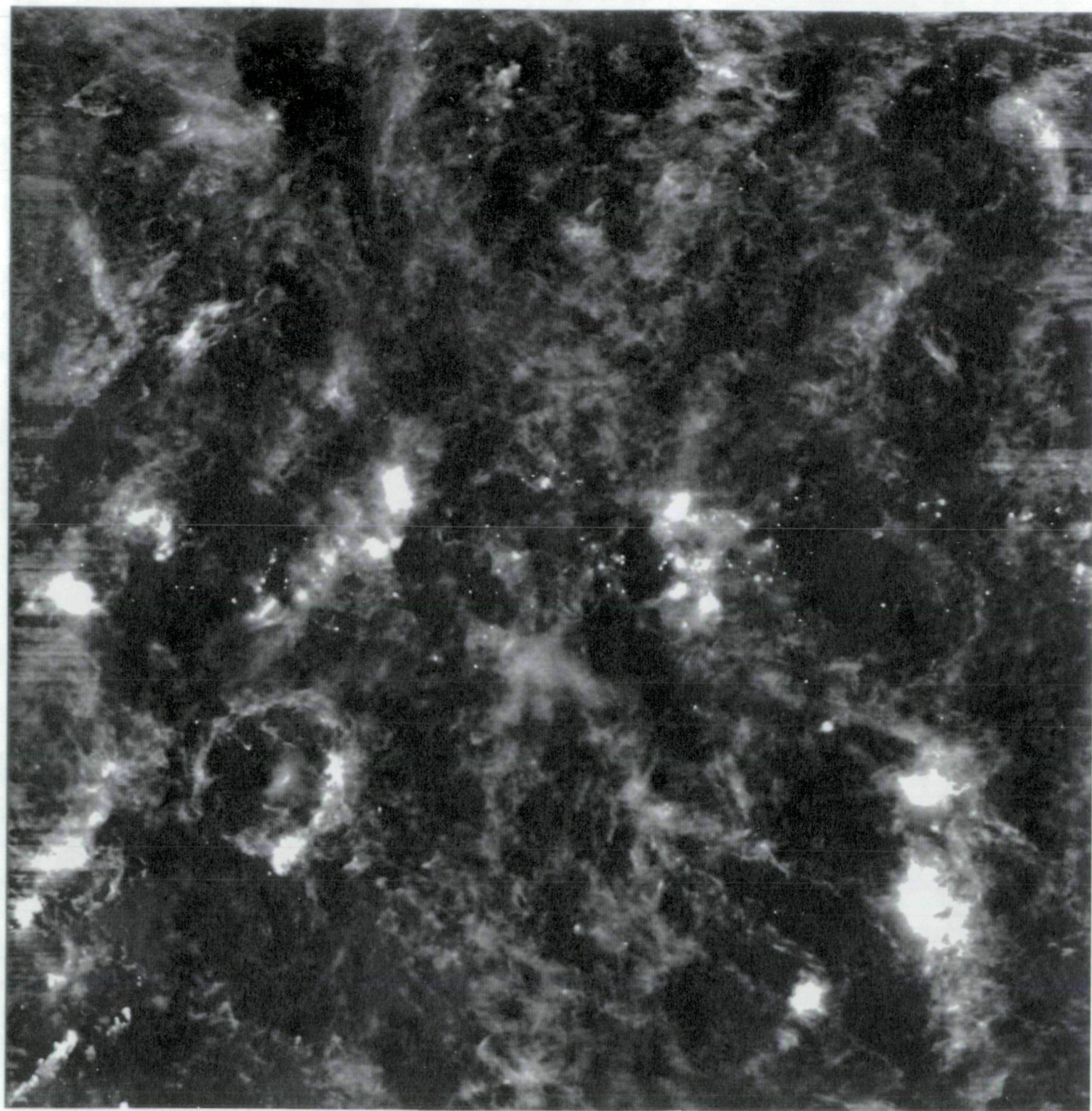


Fig. 3.4(e)

$$l = 180^\circ$$

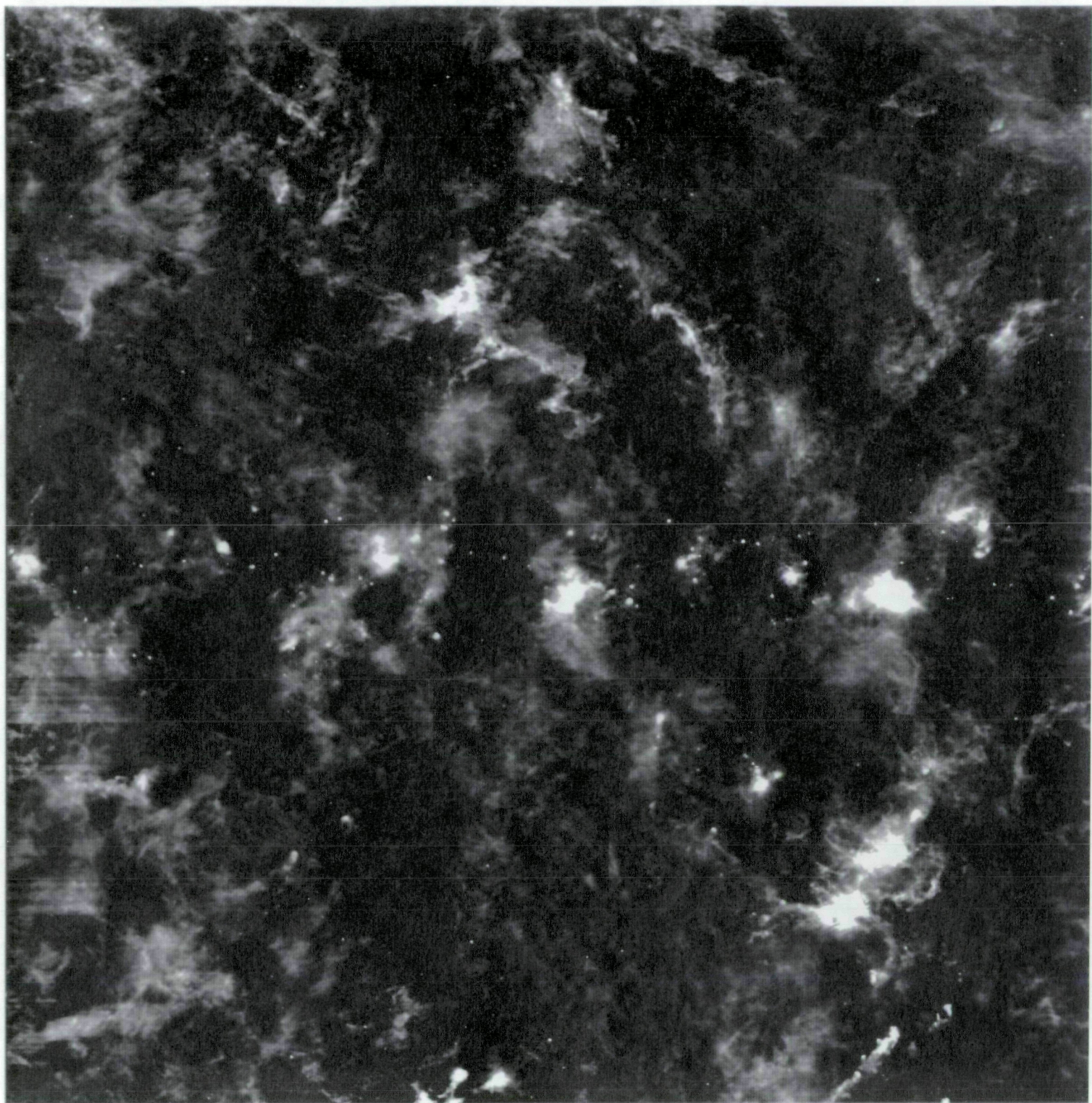


Fig. 3.4 (f)

$$l = 225^\circ$$

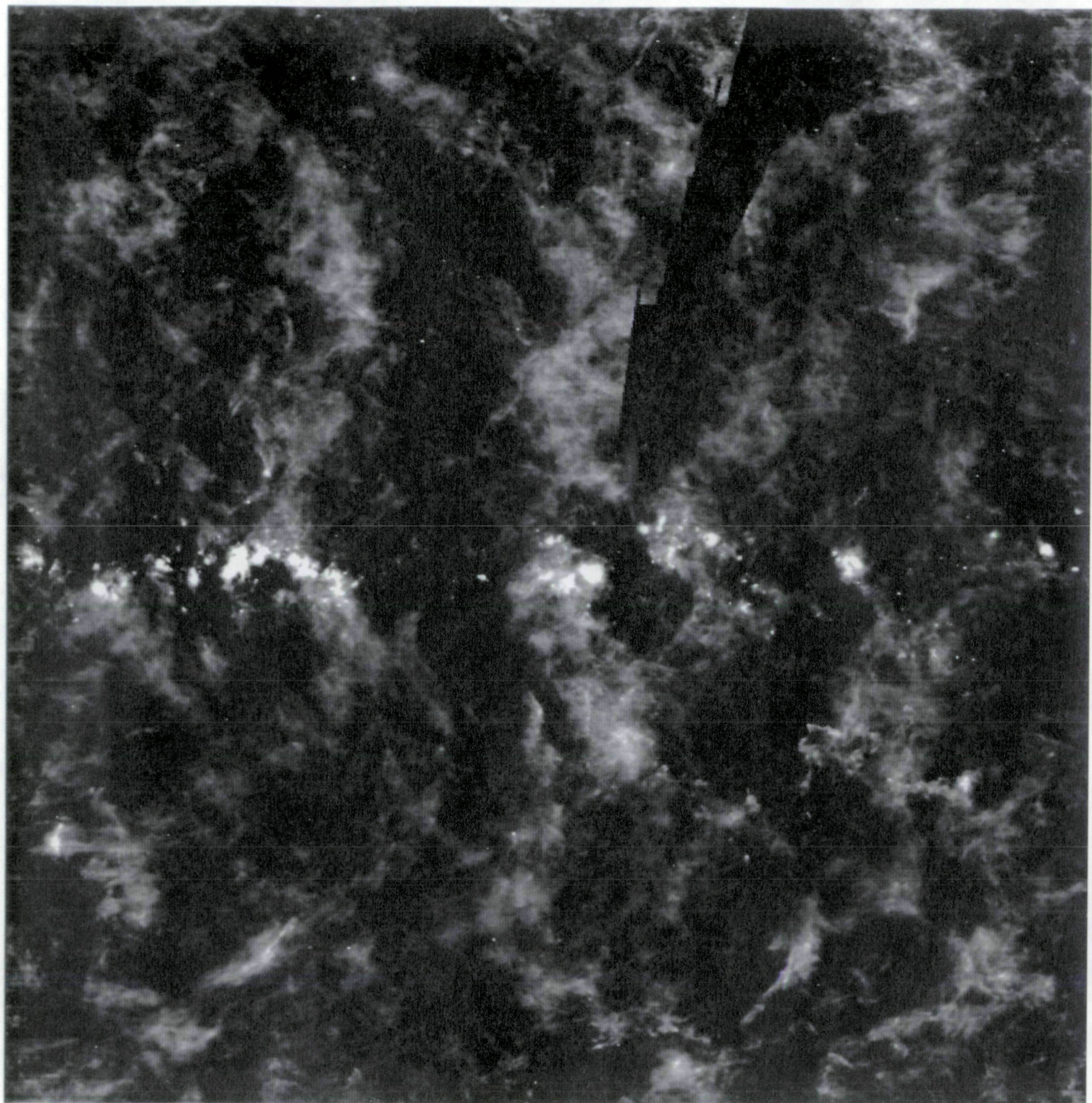


Fig. 3.4(g)

$$l = 270^\circ$$

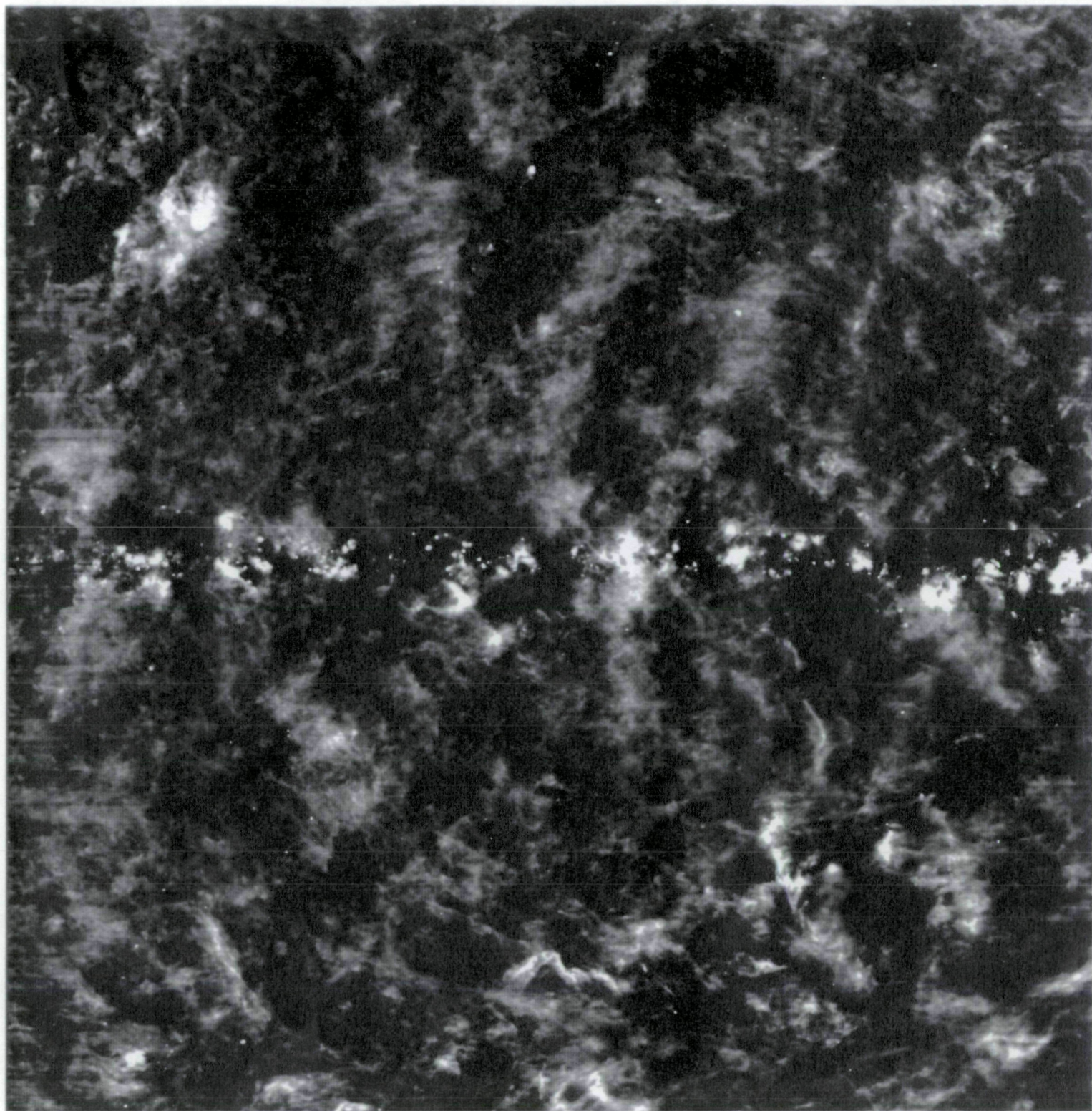


Fig. 3.4(h)

$$l = 315^\circ$$

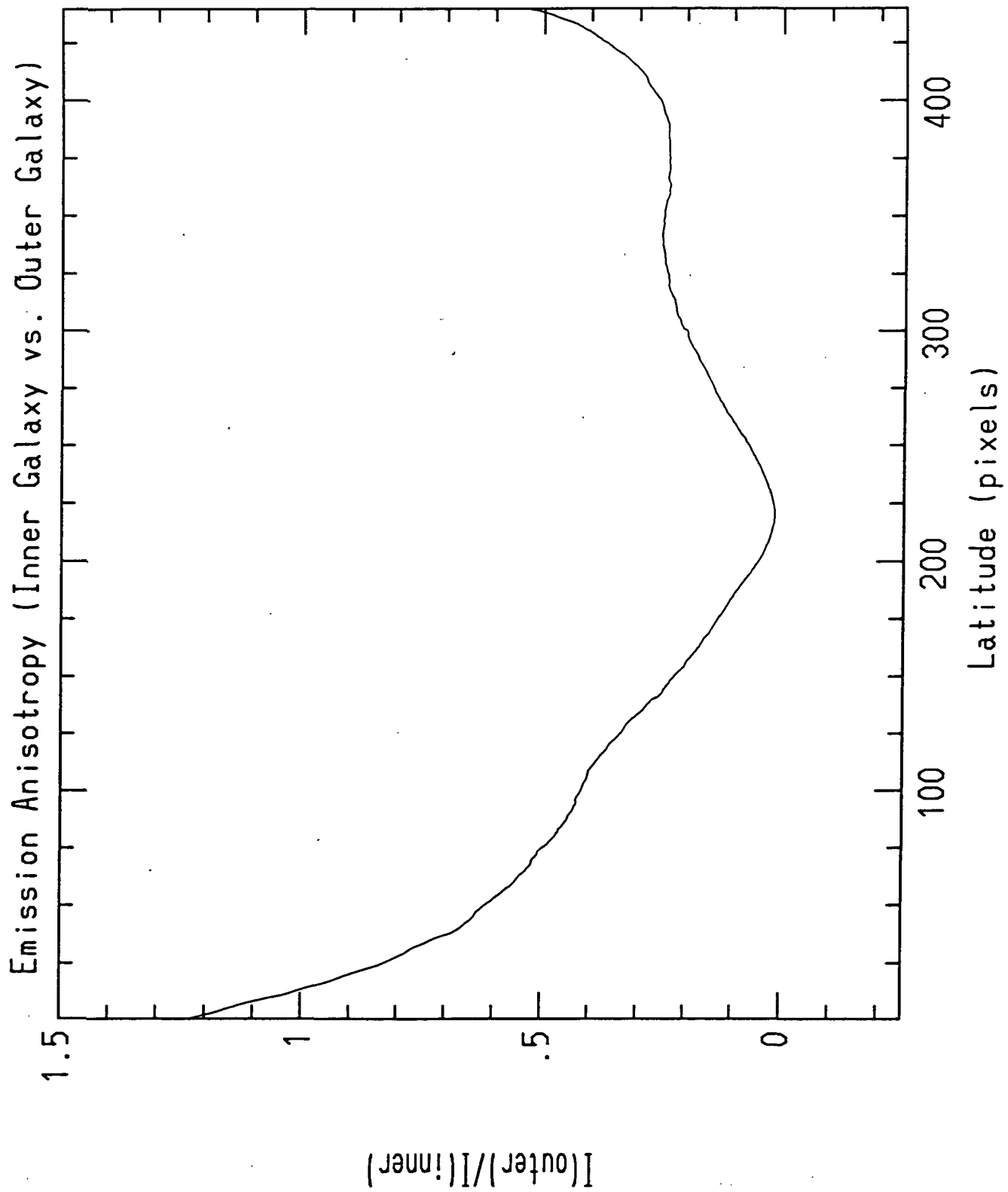


Fig. 3.5

4. Evaluation of the Spatially Filtered Data

The median-normalizing spatial filter (MNSF) was developed to eliminate the strong midplane emission found in FIR maps of the Milky Way, thereby enhancing the fine-scale FIR structure at all latitudes. Evaluation of its effects was investigated by Dr. Wall using the IRAS/BIGMAP mosaics of Galactic FIR emission. Each BIGMAP mosaic ($62^\circ \times 22^\circ$ with 0.05° pixels) was median-smoothed with a running box of dimensions ($W_f \times 1$ pix), where the filter width W_f was chosen in this case to be 15° (300 pix) in longitude. The resulting median-smoothed image was then divided into the original map, thereby producing a median-normalized map of FIR emission enhancements and deficits. The MNSF technique goes beyond traditional unsharp masking techniques, because it accentuates fine-scale structure while de-emphasizing the overwhelming brightness of the Galactic plane.

Assessing the reality of Galactic structures visible in the filtered maps requires a detailed understanding of the MNSF technique. To this end, a simulated image of the FIR emission from the Galactic plane was generated with one or two circular "blobs" representing the fine-scale structure. The MNSF processing then applied to this simulated image to examine the effect on the blobs. The Galactic plane emission was approximated by the following:

$$I(b) = I_0(b) + I_1(b),$$

where

$$I_0(b) = A_0 * [1 - \exp(-|b|/b_0)] * \operatorname{cosec}(|b|),$$

and

$$I_1(b) = A_1 * \exp(-(b/b_1)^2),$$

and where b is the Galactic latitude. The various parameters — A_0, b_0, A_1, b_1 — were chosen so that $I(b)$ would approximate the IRAS μm slice across the Galactic plane. That is, $A_0 = 15 \text{ MJy/Sr}$, $b_0 = 0.5^\circ$, $A_1 = 19,000 \text{ MJy/Sr}$, and $b_1 = 0.2^\circ$.

The fine-scale structure was approximated by one or two circular features, "blobs," added to the map containing the simulated Galactic plane. The MNSF processing was applied, and the effect on the blobs was examined.

The MNSF processing produces images consisting of intensity ratios of overall structure to large-scale structure. Values of unity in the filtered images represent positions which have only large-scale structure in the original unfiltered images. Deviations from unity represent positions where fine-scale structure is present: as depressions, for values less than unity, and as excesses, for values greater than unity. (Note that only excess, and not depressed, fine-scale structure was considered, since the blobs were added to, and not subtracted from, the simulated Galactic plane emission.) The single-blob simulations gave the expected result that, after filtering, the full circular outline (depicted as contours with levels exceeding unity) of the blob remained only for blobs with diameters less than or

equal to half of W_f . For larger diameter blobs, only the northern and southern portions of the full circular outline "survived" the filtering process.

Simulations involving more than one blob showed that, in some cases, image artifacts can result from the spatial filtering. For example, by adjusting the size and separation of two blobs one can produce a "ringing" or "echo" between them, manifested as an artificial depression in the spatially filtered image. To describe the cases where artifacts occur for two blobs at the same Galactic latitude, we define a parameter X

$$X = \min[W_f + R_1 + R_2 - S, 2 * (R_1 + R_2)],$$

where W_f is the width in Galactic longitude of the median smoothing window, R_1 and R_2 are the radii of the two blobs, and S is their separation (all in degrees). An echo will occur between the blobs if

$$X \geq W_f/2.$$

According to this criterion, a filter width of $W_f = 15^\circ$ will produce echos for sizes less than 2° if separations are less than 4° , and for sizes greater than 2° when separations are less than $2 \times$ the size. By varying the filter width (i.e., trying W_f different from 15°), one can evaluate the filtered images in terms of possible artifacts on all scales. For the filtered images presented herein, most of the prominent fine-scale features have sizes less than 5° and separations exceeding twice the size (see next section). Therefore, the fine-scale structure reported herein is for the most part valid.

5. Spatial Statistics of the FIR "Froth"

As shown in Section 3, the MNSF processing of the FIR mosaics produces a complex "froth" of filaments, shells, loops, and voids that extends through the Galactic midplane to high positive and negative latitude. Visual inspection of the spatially filtered maps gives the impression of structure on many scales, i.e. self-similar structure. To quantify this structure for comparison with better-known interstellar structures (e.g. molecular clouds, diffuse clouds, etc), we have determined the key parameters which describe the spatial statistics inherent to the images.

The analysis of spatial statistics and fractal properties of the images is based on the extension of fractal Brownian motion to higher dimensions (Barnsley et al. 1988). Let $X = (x_1, x_2, \dots, x_n)$ and $Y = (y_1, y_2, \dots, y_n)$ be points in an n -dimensional image, and $v(X)$ the value of a random process at those points. Then a generalized fractal Brownian random field has the properties that the increments, $v(X) - v(Y)$, are Gaussian distributed with zero mean, while the incremental variances obey:

$$E\{[v(X) - v(Y)]^2\} = A * (|X - Y|^2)^H,$$

where $|X - Y|$ is the distance norm, A is a constant of proportionality, $E\{\}$ stands for expectation, and the scaling parameter H characterizes the fractal properties with $0 <$

$H < 1$. The scaling parameter H is related to the Hausdorff fractal dimension of the hyper-surface $v(X)$ embedded in $n+1$ dimensions by

$$D = n + 1 - H.$$

Let $V(k)$ be the Fourier transform of $v(X)$, where $k = (k_1, k_2, \dots, k_n)$ is the n -dimension vector of wavenumbers (spatial frequencies). Then the power spectral density is obtained as

$$S(k) = V(k) * \text{conj}(V(k)),$$

where $S(k)$ is basically the amplitude-squared of wavenumber k , ignoring phase. Assuming that $v(X)$ is isotropic, the theory of fractal Brownian fields gives

$$E(S(k)) = C * f^{(-\beta)},$$

where the power law exponent $\beta = 2H + n$, radial wavenumber $f = |k| = \text{sqrt}[\text{sum}(k)]$, and C is a constant of proportionality. Solving for H in terms of β and substituting in above equation for D gives

$$D = 3n/2 + 1 - \beta/2,$$

a relation between the power spectral density behaviour and fractal dimension.

The above theory was applied to the IRAS/ISSA $100\mu\text{m}$ mosaics ($n=2$) by using

$$v(X) = \log\{I(X)\} - \log\{W[I(X)]\},$$

where $W[I(X)]$ is the median-smoothed mosaic. Subtraction of the $\log W[I(X)]$ image is equivalent to applying the MNSF to the original $I(X)$ image, in that it effectively eliminates all of the large-scale background variations — e.g. the strong *cosecant b* brightening towards the Galactic midplane.

To estimate $E(S(k))$ of the power spectral density, the amplitudes of $S(k)$ are averaged over annular regions of $f < |k| < f + 2$. The isotropy assumption is checked by comparing the power spectra in longitude and latitude, $S(k_1, 0)$ vs. $S(0, k_2)$. Unlike the situation before spatial filtering, the longitudinal and latitudinal spectra of the spatially-filtered images are found to exhibit the same behaviour for all images (except the one containing Orion). The directional invariance in $S(k_1, k_2)$ supports the assumption of isotropy and permits the averaging over annular regions.

As shown in **Figure 5.1**, the spatial power spectra of the fine-scale FIR emission are characterized by a power-law exponent of $\beta = 3$, where $0.8 < f < 4$ cycles/degree (wavelengths of 0.25° to 1.25°), and of $\beta = 4$ for higher spatial frequencies where resolution limits begin to matter. Power-law exponents of $\beta \approx 3$ have been obtained from analysis of isolated molecular clouds and diffuse clouds at high Galactic latitude. For example, Gautier et al. (1992) obtain power-law exponents of 2.9 and 3.2 respectively for the $100\mu\text{m}$ emission in the diffuse North Polar and Ursa Major clouds, 3.2 in the Taurus and Chamaeleon molecular clouds, and 3 in a dim cirrus area.

Such similitude in the power spectra is found despite the fact that the FIR fine-scale structure at low Galactic latitude is the result of both nearby and distant emitting features (especially towards the inner Galaxy). Apparently, the self-similar nature of the emitting structures causes features at different distances to add spectral power as a function of angular scale, such that the logarithmic power law remains unaffected. In other words, a given range of angular spatial frequencies contains different sized structures from nearby and distant objects which are distributed according to the same self-similar power law.

Even more interesting is the behavior at lower frequency ($f = 0.1$ to 0.8) and longer wavelength (1.25° to 10°), where the exponent 'flattens' to $\beta = 2.5$. This change in slope probably indicates a change in the characteristic structure — the larger-scale emission featuring more prominent peaks and voids.

The power-law exponent of $\beta = 3$ yields a fractal dimension of $D = 4 - \beta/2 = 4 - 3/2 = 2.5$ indicating a fractal scaling property of the data for the range $0.8 < f < 4$. For the higher f range (wavelengths less than 0.25°), $D = 2$ as might be expected, since the resolution of IRAS data is somewhat less than the pixel size of 0.05 degrees. For the lower f range (wavelengths greater than 1.25°), the fractal dimension is $D = 2.75$, which implies an enhancement of prominent structure. This is borne out by the fact that structure over this range of angular scales can be described in words (e.g. loops, filaments, shells and voids). To understand more about these anecdotal structures, a more detailed analysis is required (see next section).

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 Gautier, T. N. III, Boulanger, F., Perault, M., and Puget, J. L. 1992, AJ, 103, 1313

FIGURES:

Figure 5.1. Spatial power spectrum of the spatially-filtered FIR emission from the central ($60^\circ \times 60^\circ$) of the Galaxy. Similar behavior is evident throughout the Galaxy. The low and high spatial frequency domains are characterized by significantly different power-law exponents, indicating different structural arrangements. This could be due to different dynamical inputs organizing the small and large-scale structures (e.g. turbulence and diffusion on small scales vs. macroscopic winds and shock fronts on larger scales).

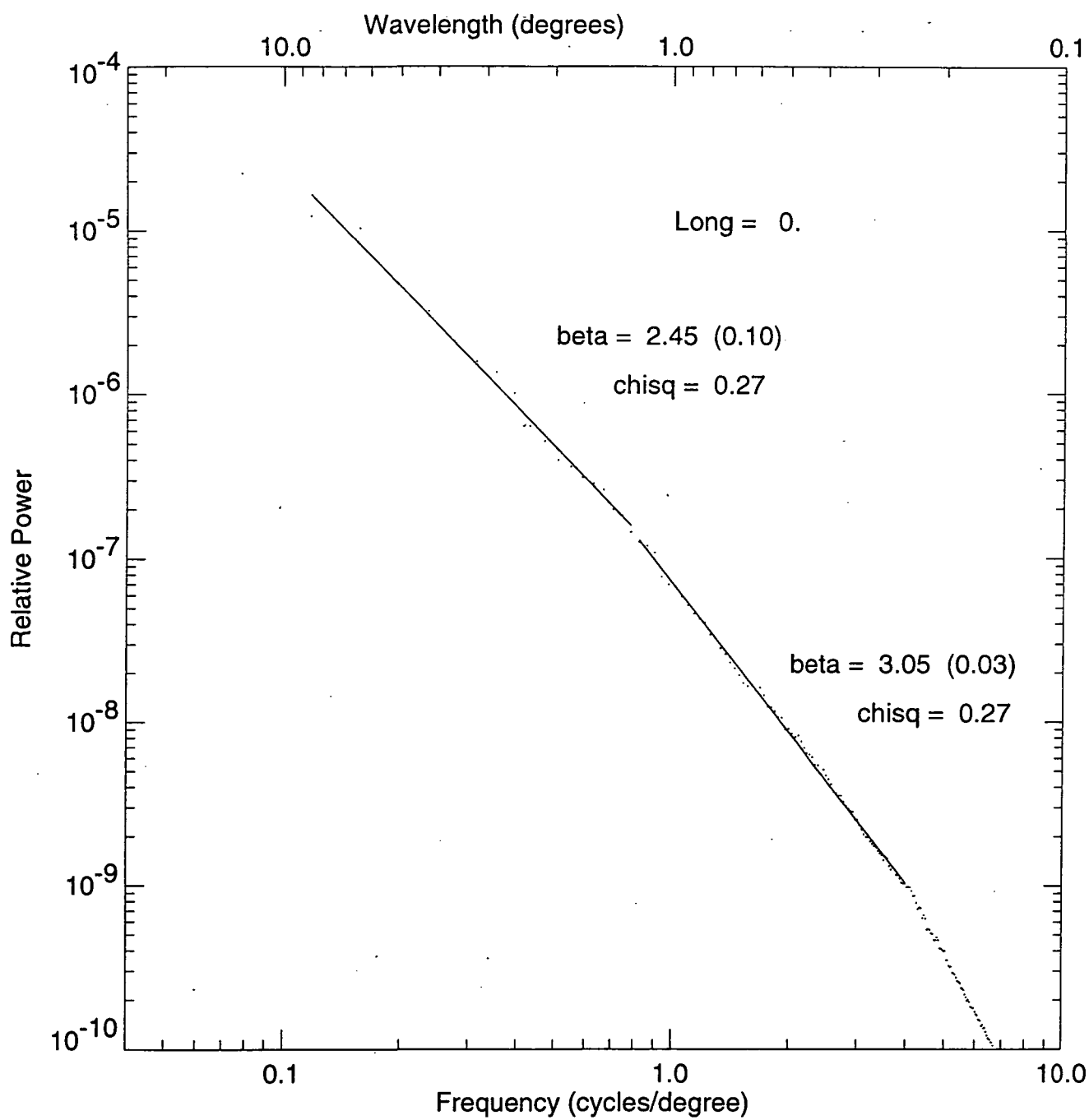


Fig. 5.1

6. Interstellar Counterparts

In Section 3, we presented the FIR fine-scale structure and established that the filamentary and shell-like structure is co-extensive with the smoothly varying dust emission in the disk. In Section 5, we showed that the FIR fine-scale structure is self-similar with a spatial power-law exponent of -3 and a fractal dimension of 2.5 — similar behavior to that found in isolated cirrus and molecular clouds. Determining the interstellar counterparts to this emission is more problematic. This is because the dust emission is seen in projection, with no Doppler-shifted kinematic information which could be used to constrain its Galactocentric and Heliocentric distances. The emitting dust could reside in one or all 3 of the phases which dominate the mass of the interstellar medium — namely the cold molecular phase traced by CO emission, the cool atomic phase traced by HI emission, and the warm ionized phase traced by radio-continuum emission.

In an initial effort to find interstellar counterparts to the FIR “froth,” images of the fine-scale structure in the inner Galaxy were directly compared with contour diagrams of spatially filtered CO emission (Waller and Boulanger 1994; see Appendix A). Positions and sizes of nearby dark clouds and supernova remnants were also plotted. Correlations between the CO emission and the FIR froth were evident near the Galactic plane, but became less frequent at higher latitudes — due perhaps to the poorer CO sensitivity.

To our surprise, the nearby dark clouds did not show up in the FIR froth. We speculate that the nearby dark clouds are significantly colder than most of the emitting dust in the inner Galaxy. The warmer dust in the molecular ring probably dominates the emission observed at $100\ \mu\text{m}$ and shorter wavelengths, overwhelming the dimmer foreground emission from the colder dark clouds. With some exceptions, the supernova remnants do not appear to be correlated with either the FIR enhancements or the FIR voids. From these comparisons, we inferred that the most common counterparts to the FIR froth would be found in comparisons with the warm atomic and cool atomic components.

Such correlations were sought between the IRAS/BIGMAP mosaics of the Milky Way ($62^\circ \times 22^\circ$ mosaics centered at 0, 60, 120, 180, 240, and 300 degrees of longitude) and maps representing gas emission: radio-continuum maps (sampling ionized gas, and nonthermal emission from supernova remnants), HI 21-cm line maps (sampling atomic gas), and CO 2.6-mm line maps (sampling molecular gas) (see Section 2). The correlation search entailed running a square box simultaneously over two maps from different datasets and, at each position, assigning a confidence to the correlation.

For example, to test the correlation between an IRAS $100\ \mu\text{m}$ map and the radio-continuum map, we first spatially filtered maps of the IRAS and radio-continuum emission (rebinned to have the same resolution) (see Figure 6.1). We then centered a $2.5^\circ \times 2.5^\circ$ box at each position in the smoothed $100\ \mu\text{m}$ map and listed the intensities occurring within that box. The corresponding radio-continuum intensities within the same box were then listed. A plot of the listed $100\ \mu\text{m}$ intensities versus the listed radio-continuum intensities was finally assessed for correlation using the Spearman rank-order correlation test (Press 1986).

The Spearman test was deemed most appropriate for testing correlations because it makes no assumption as to the exact nature of the correlation (e.g., it does not assume

a linear correlation). The result of the correlation test is a confidence level, where a confidence level of 0.0 means no confidence in the correlation and a level of 1.0 means complete confidence in the correlation. The confidence level is then recorded in a map of correlation confidences and the $2.5^\circ \times 2.5^\circ$ box is moved to the next position within the 100 μm and radio-continuum maps. In this way, an entire map of correlation confidences is built up. The whole process was then repeated between the 100-micron map and the HI 21-cm line map, and repeated again for the 100 μm map and the CO 2.6-mm line map. Correlations of the 100 μm map with all 3 components of the ISM were thus established.

From the correlation confidence maps, the infrared fine-scale structure maps were encoded with colors according to the corresponding component of the ISM (see FIGURE 6.2). Using the above example, the 100 μm map would show red, green, and blue structures depending on whether the correlated structures correspond to ionized, atomic, or molecular gas, respectively. These color-coded correlation maps also show many regions of "mixed" color: yellows, purples, and whites. The mixed color regions are correlated with more than one interstellar component. The yellow regions, for instance, represent positions where the 100 μm fine-scale structure correlates with the ionized (encoded red) and atomic gas (encoded green) fine-scale structure simultaneously. Color-coded correlation maps were generated for all the Galactic plane mosaics at all four wavelengths: 12, 25, 60, and 100 μm . The color-coded correlation maps were created in 4 steps:

- a.) All IRAS and radio maps were rebinned to 0.5 deg pixels. This ensures that all maps have the same effective spatial resolution. The chosen resolution reflects that of the poorest resolution data: the radio and millimeter-wave data.
- b.) The median normalizing spatial filter (MNSF) was applied to all the rebinned maps (see Figure 6.1).
- c.) The correlation confidence maps were created using a $2.5^\circ \times 2.5^\circ$ running box. This size box corresponds to 25 points for testing correlations. This number of points was deemed optimum because fewer points would give correlation confidences based on small-number statistics and more points would require a larger running box, increasing the disparity between the map resolution and the resolution of the "coloring" in the final color-coded correlation map.
- d.) The color-coded maps were generated from the correlation confidence maps. Each color-coded map was created from separate red, green, and blue maps, each of which were created by masking off positions in the filtered IRAS map that correspond to correlation confidences below a critical level (chosen to be 0.90). To create a 100 μm color-coded correlation map, for example, the red map was generated by setting all positions to zero in the 100 μm map that had correlation confidences with respect to the radio continuum less than 0.90. Similarly, the green map was generated by setting all positions to zero in the 100 μm map that had correlation confidences with respect to the HI 21-cm line less than 0.90. The blue map was generated by setting all positions to zero in the 100 μm map that had correlation confidences with respect to the CO 2.6-mm line less than 0.90. The red, green, and blue maps were then combined using an appropriate color monitor and color printer (see Figure 6.2).

Comparing the color-coded correlation maps at one IRAS wavelength with those at other wavelengths provides insights into the physical processes associated with the FIR fine-

scale structure. For example, preliminary inspection indicates that the $60\ \mu\text{m}$ correlation maps have proportionately more red (correlated radio-continuum emission) than the $100\ \mu\text{m}$ correlation maps. The trend of proportionately increasing radio-continuum correlations continues at the shorter wavelength IRAS bandpasses ($25\ \&\ 12\ \mu\text{m}$). This behavior can be attributed to the greater sensitivity of the shorter wavelength bandpasses to higher temperature dust grains, such as those found in the ionized regions which produce radio free-free continuum emission.

Analysis of the correlated HI and CO structures is especially important, because the spectral-line emission contains Doppler-shifted kinematic information which can be used to determine kinematic distances of the structures (based on a kinematic model of the rotating Milky Way). Towards this end, a tabulation of correlated interstellar counterparts to the $100\ \mu\text{m}$ fine-scale structure is listed in Table 2. The position, size, and counterpart of each correlation is included. For simultaneous correlations, a ranking is presented based on inspection of the color-keyed correlation maps. In some instances, more than one correlated counterpart is given the same rank (tie score).

A total of 468 correlated FIR features are listed. The features include 345 HI correlations (282 of first rank), 230 radio-continuum correlations (142 of first rank), and 133 CO correlations (78 of first rank). As anticipated (Waller and Boulanger 1994 — see Appendix A), the FIR fine-scale structure away from the Galactic plane is most closely correlated with the HI and radio-continuum emission. The relatively low number of first-rank CO correlations away from the plane is probably limited by the limited sensitivity of existing CO surveys. Deeper and better-resolved CO studies of selected FIR cirrus regions reveal strong correlations between the diffuse CO and FIR emission (see Appendix A and references therein).

We anticipate that the correlated features presented herein will serve as an important basis for subsequent morphological and dynamical studies of the Galaxy's multi-phased interstellar medium. A similar correlation study of the larger mosaics presented in Sections 1 & 3 should yield even greater numbers of interstellar counterparts, whose multi-phased properties will yield important clues to the organization, ecology, and evolution of the interstellar medium.

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FIGURES:

Figure 6.1. Color-coded maps of spatially-filtered emission in the Milky Way. The spatially filtered radio-continuum emission is shown in red; the HI line emission is coded in green; and the CO line emission is coded in blue. The maps have dimensions of $62^\circ \times 22^\circ$ in Galactic longitude and latitude. They are centered at 0° latitude and longitude centers of (a) $0^\circ = 360^\circ$, (b) 60° , (c) 120° , (d) 180° , (e) $240^\circ = -120^\circ$, and (f) $300^\circ = -60^\circ$.

Figure 6.2. Color-coded maps of correlated interstellar counterparts to the $100\ \mu\text{m}$ fine-scale structure. The correlated emission is coded in red for the radio-continuum emission, green for the HI line emission, and blue for CO line emission. Each map has dimensions of $62^\circ \times 22^\circ$ in Galactic longitude and latitude. Same centers as in **Figure 6.1**. The displayed features are correlated with the $100\ \mu\text{m}$ fine-scale structure at the 90 percent confidence level.

Fig. 6.1(a)
 $l = 0^\circ$

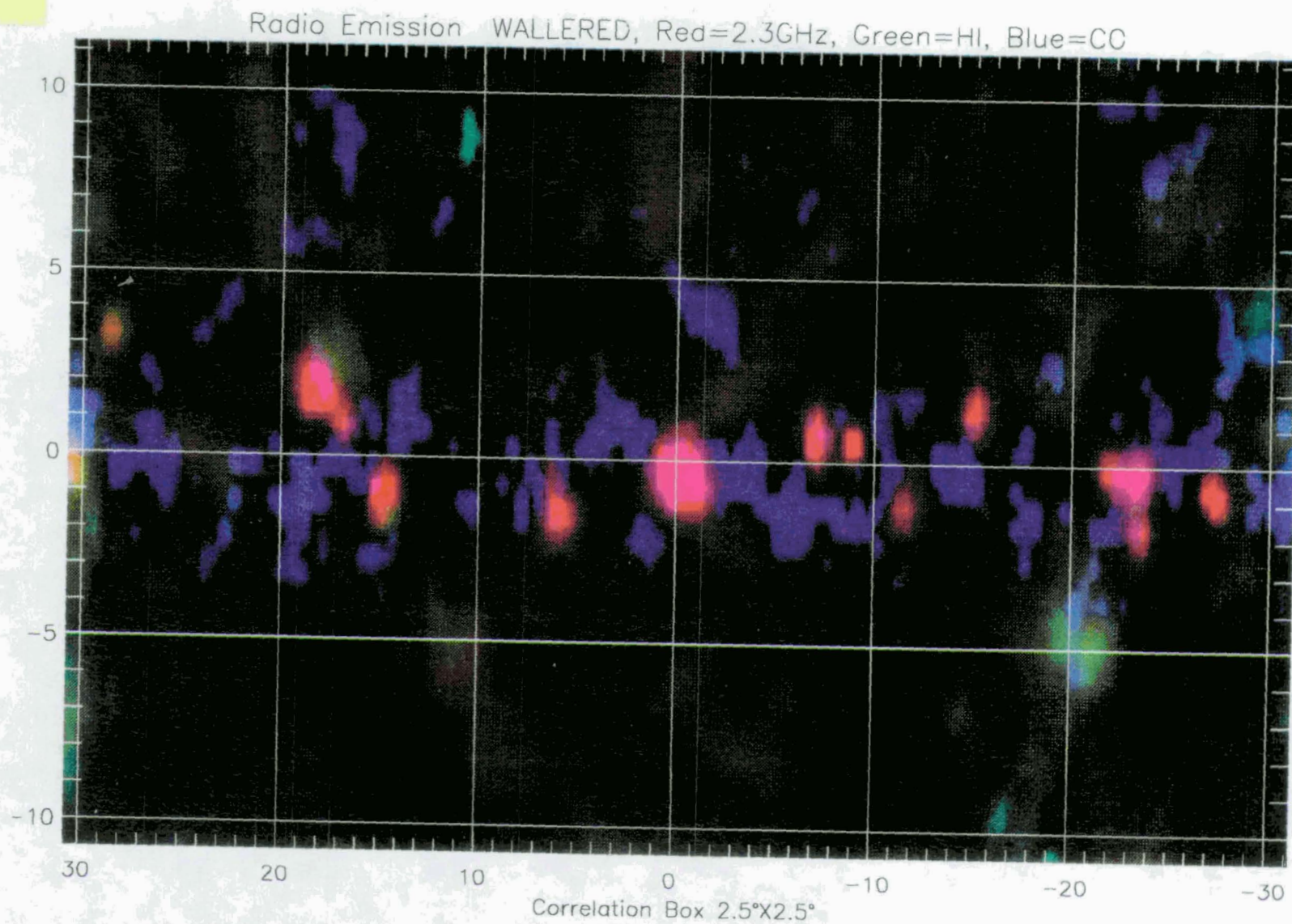


Fig. 6.1(b)
 $\lambda = 60^\circ$

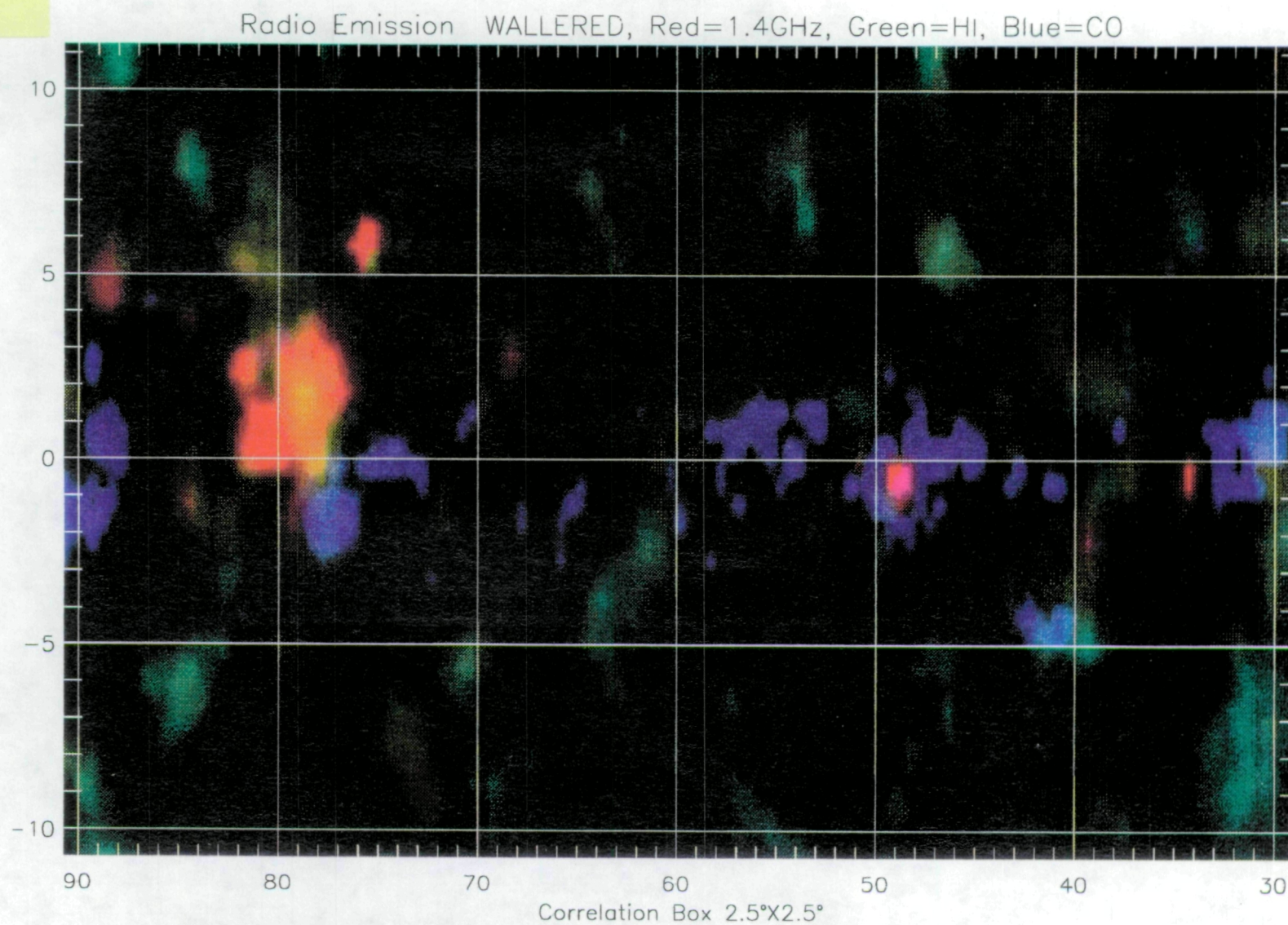


Fig. 6.1(c)
 $l = 120^\circ$

Radio Emission WALLERED, Red=1.4GHz, Green=HI, Blue=CO

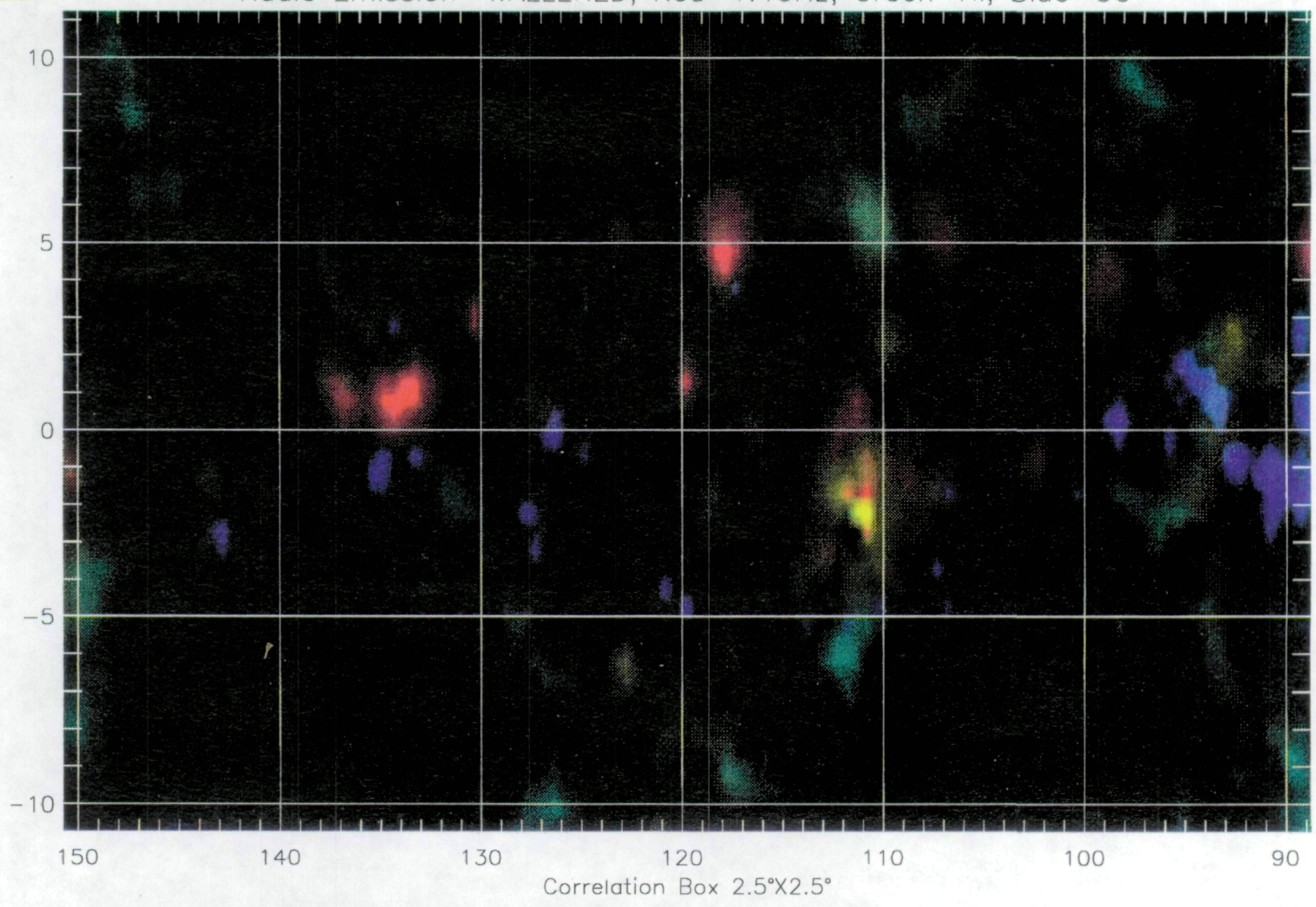


Fig. 6.1 (d)
 $l = 180^\circ$

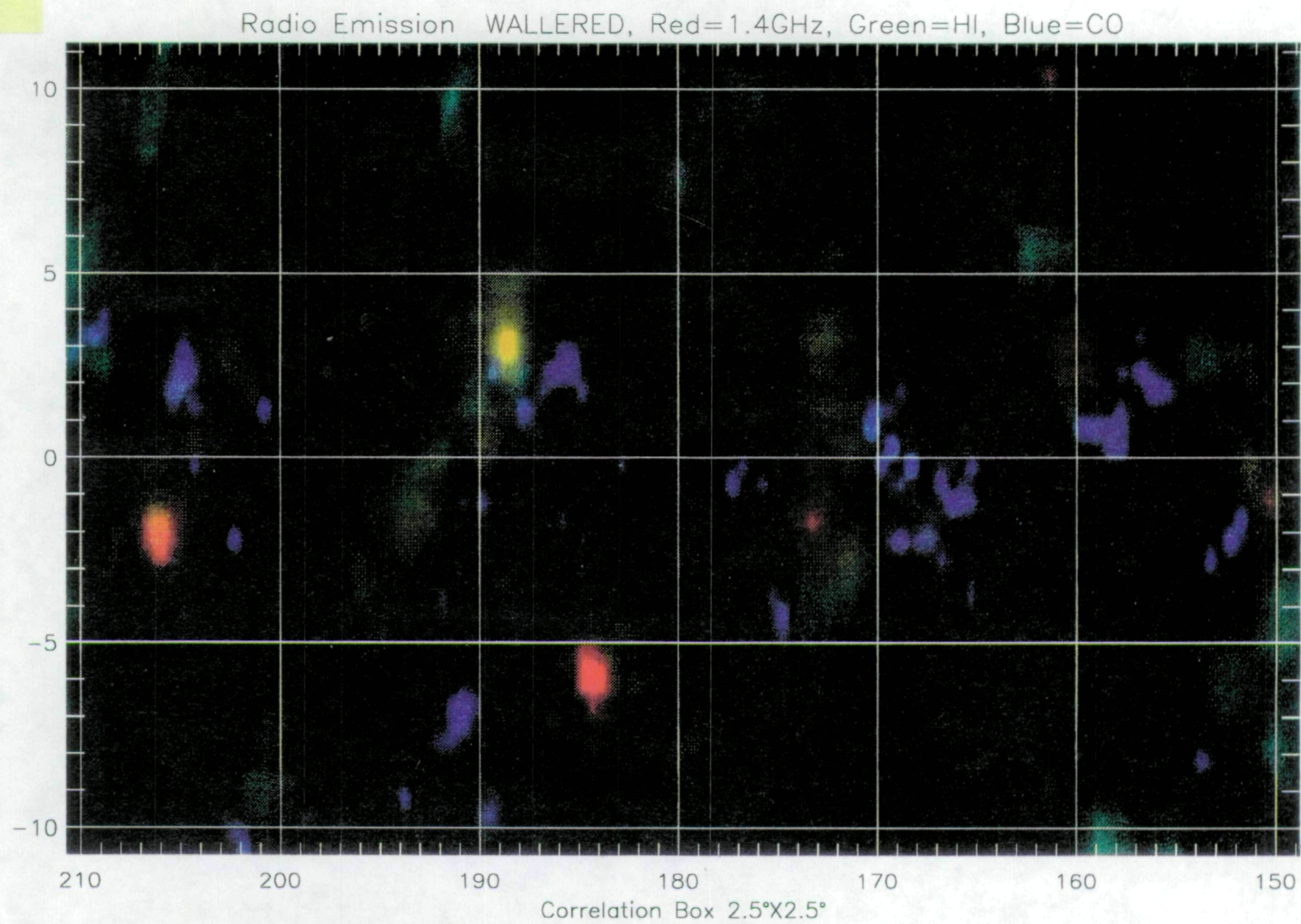


Fig. 6.1(e)
 $l = -120^\circ$
 $= 240^\circ$

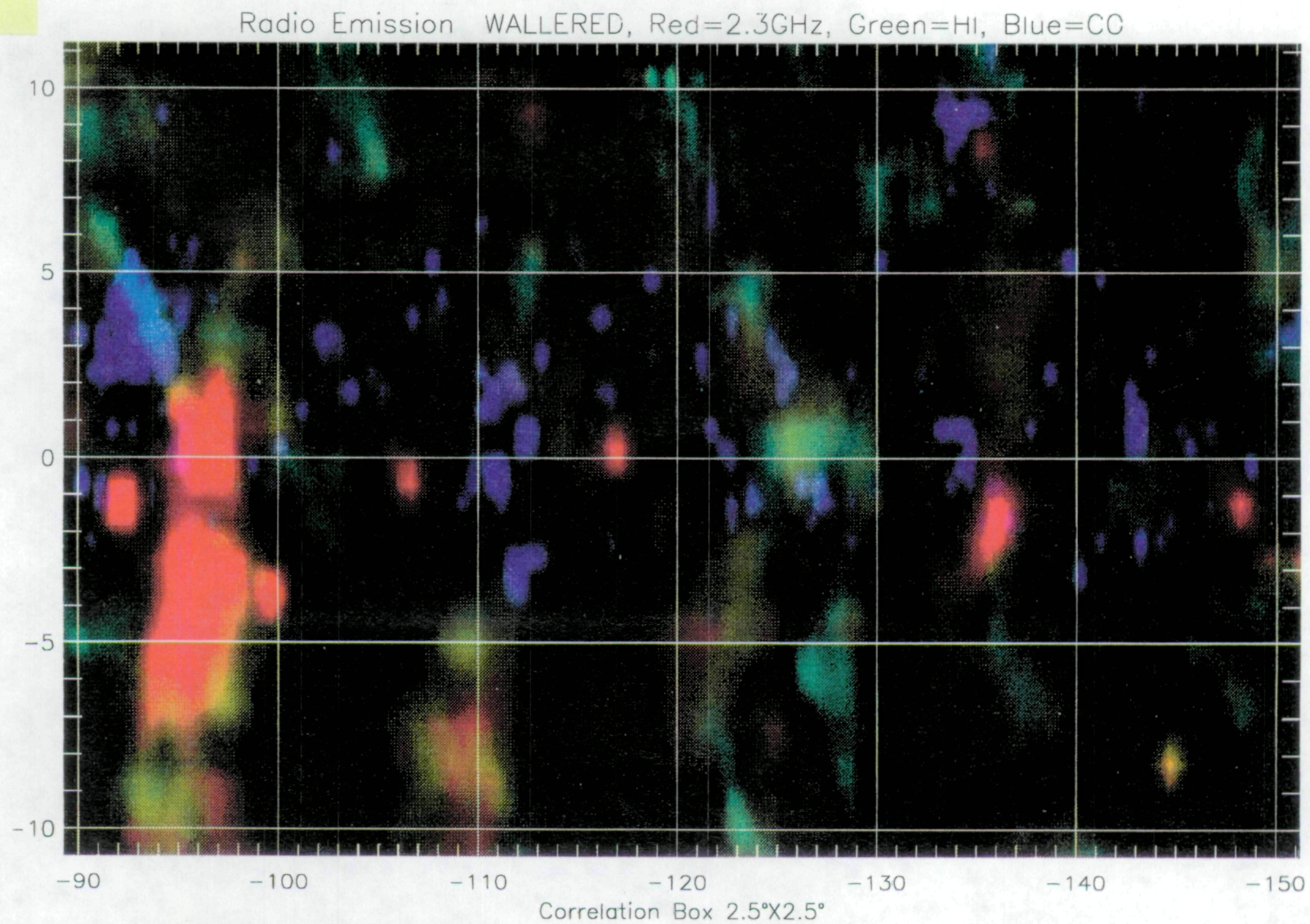


Fig. 6.1 (f)
 $l = -60^\circ$
 $b = 300^\circ$

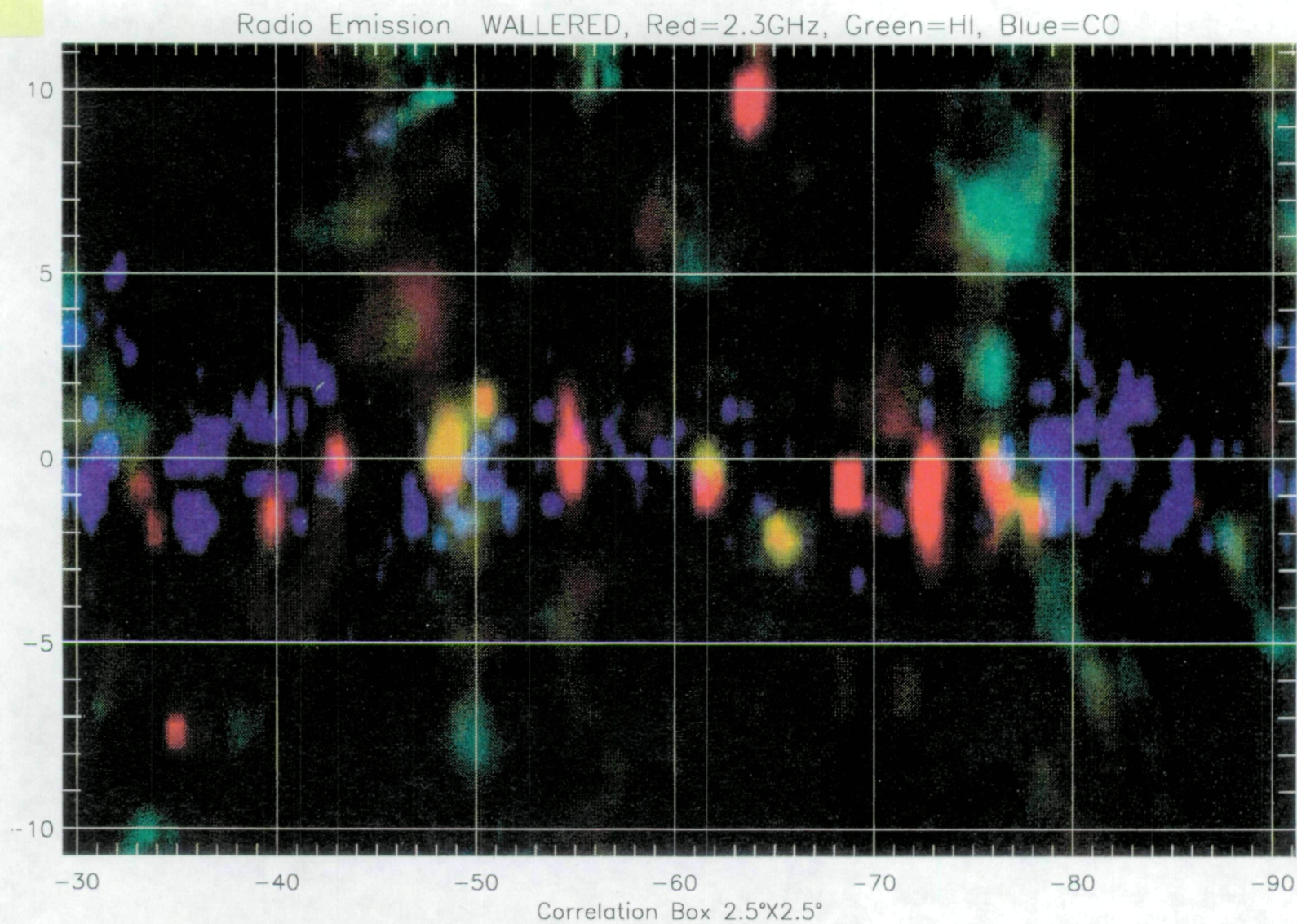


Fig. 6.2(a)
 $l = 0^\circ$

IRAS 100 μ m WALLERED, Red=2.3GHz, Green=HI, Blue=CO

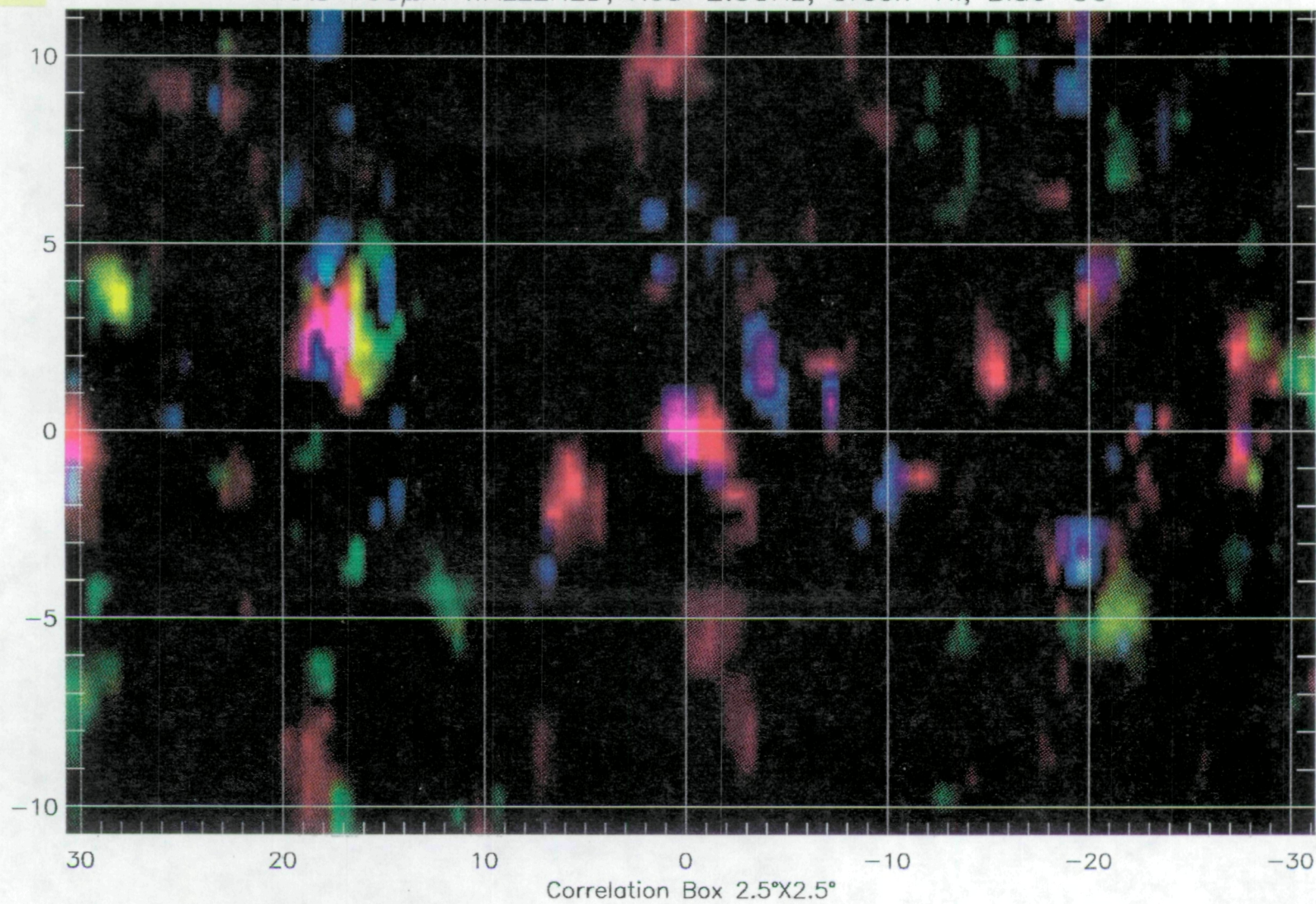


Fig. 6.2(b)
 $l = 60^\circ$

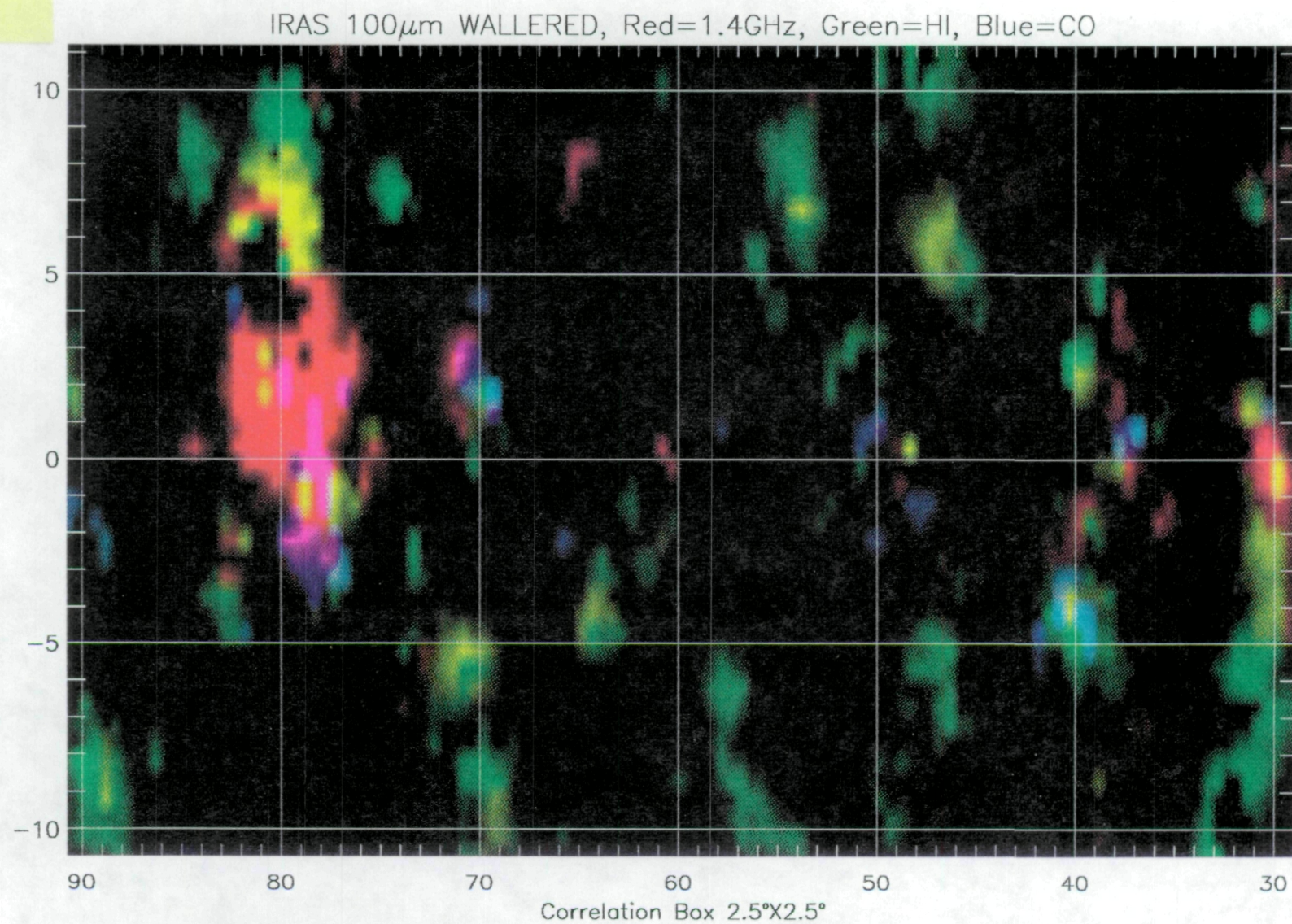


Fig. 6.2(c)
 $\ell = 120^\circ$

IRAS 100 μ m WALLERED, Red=1.4GHz, Green=HI, Blue=CO

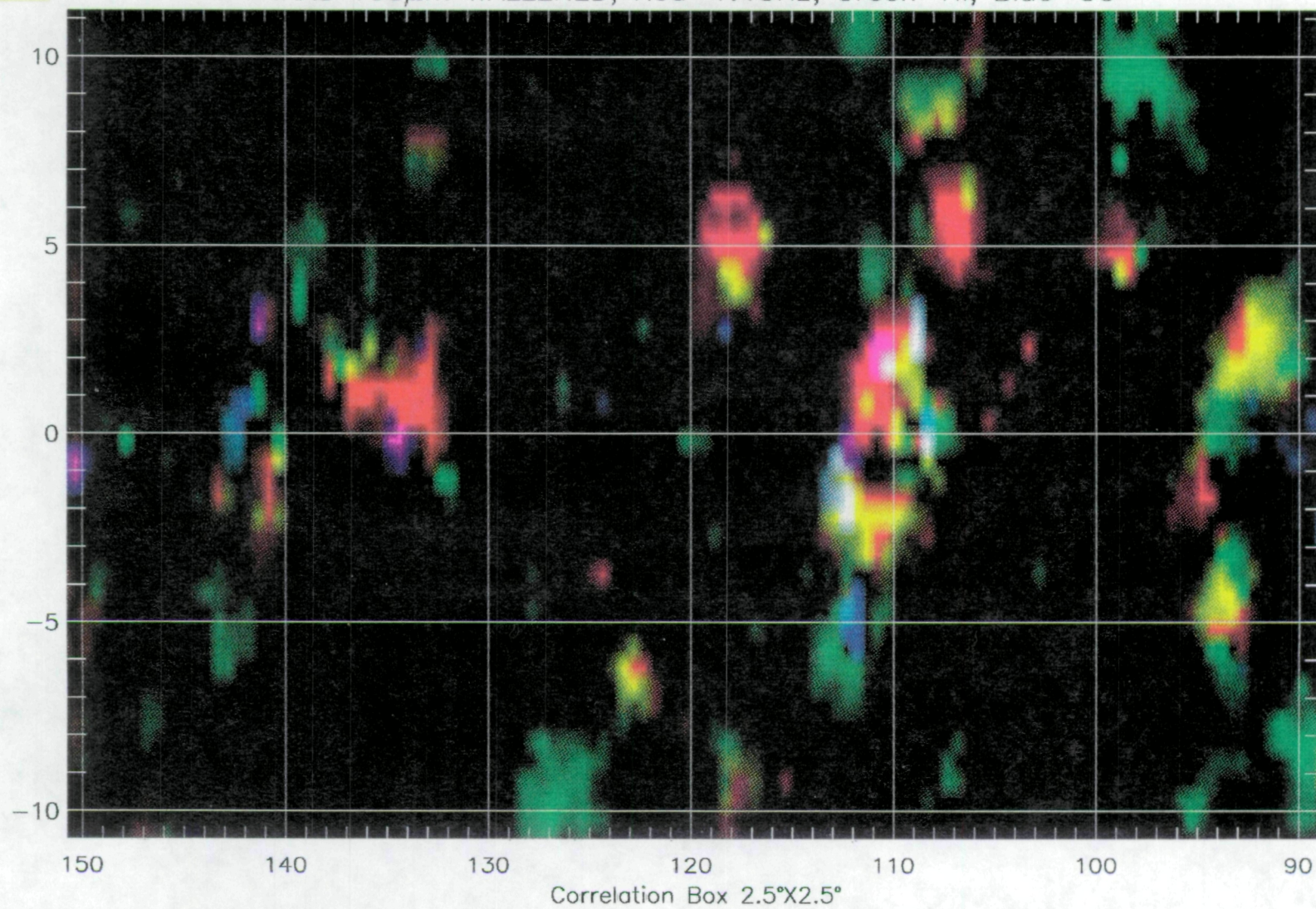


Fig. 6.2 (d)
 $\ell = 180^\circ$

IRAS 100 μ m WALLERED, Red=1.4GHz, Green=HI, Blue=CO

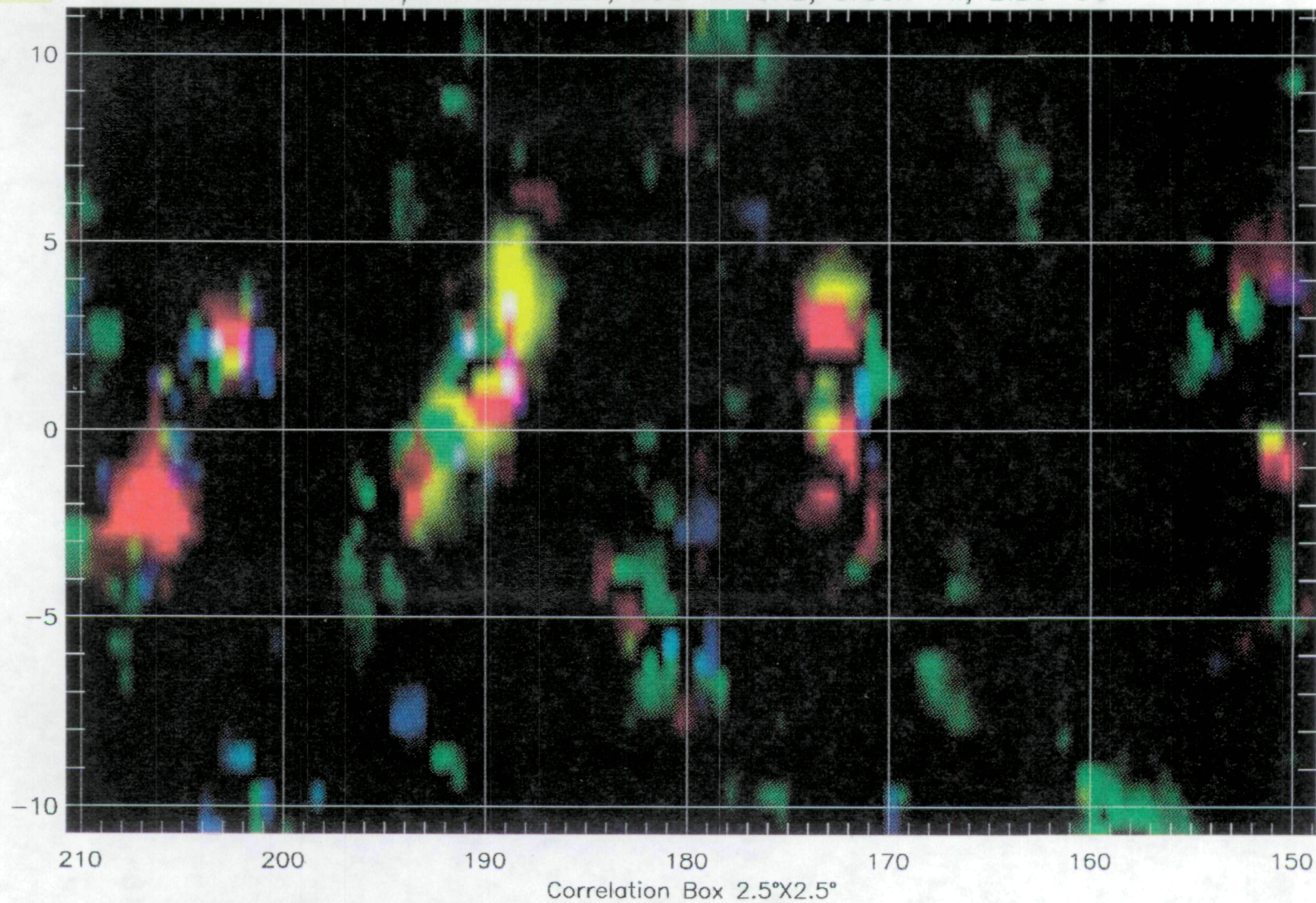


Fig. 6.2(e)
 $l = -120^\circ$
 $= 240^\circ$

IRAS 100 μ m WALLERED, Red=2.3GHz, Green=HI, Blue=CO

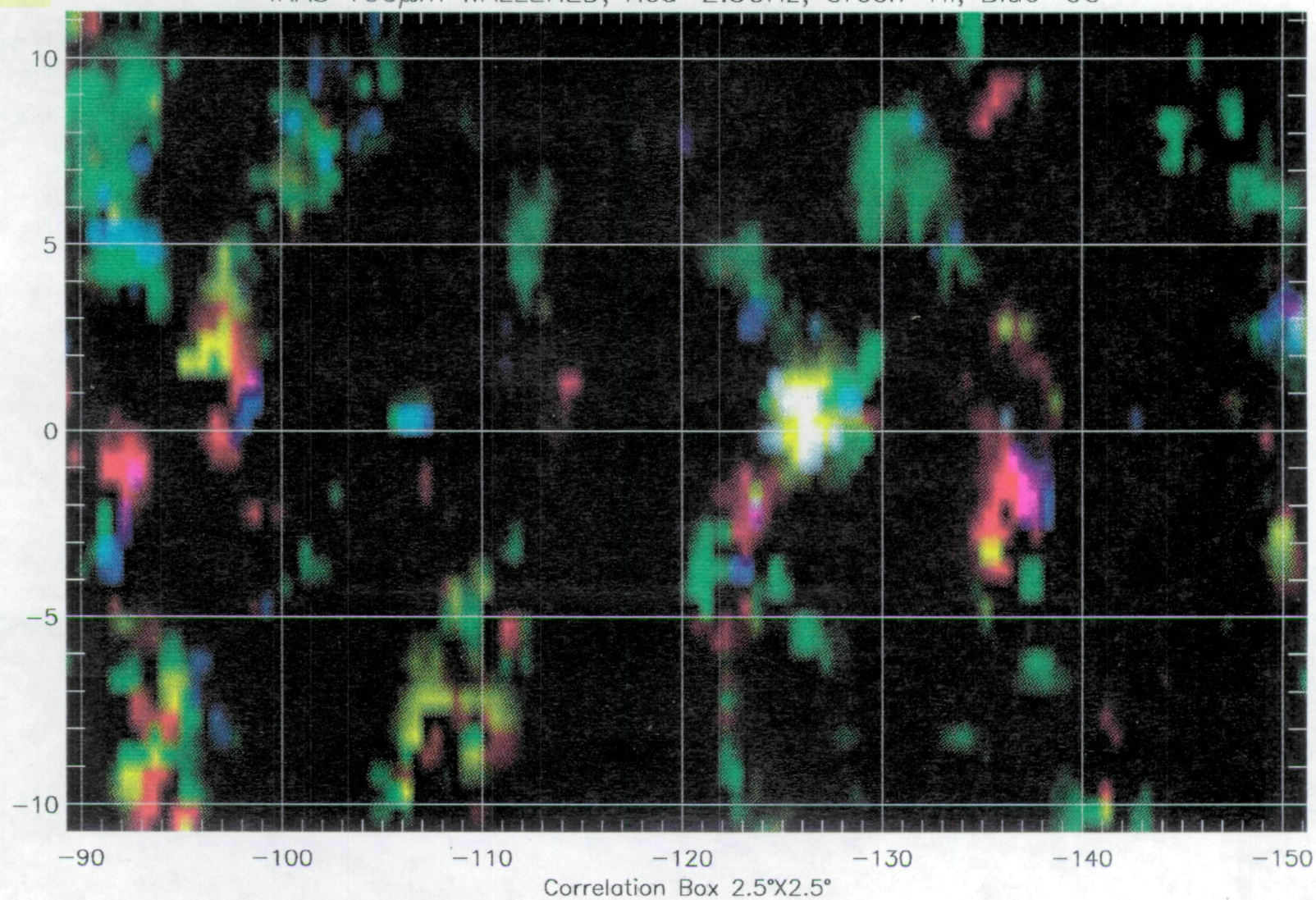


Fig. 6.2 (ℓ)
 $\ell = -60^\circ$
 $= 300^\circ$

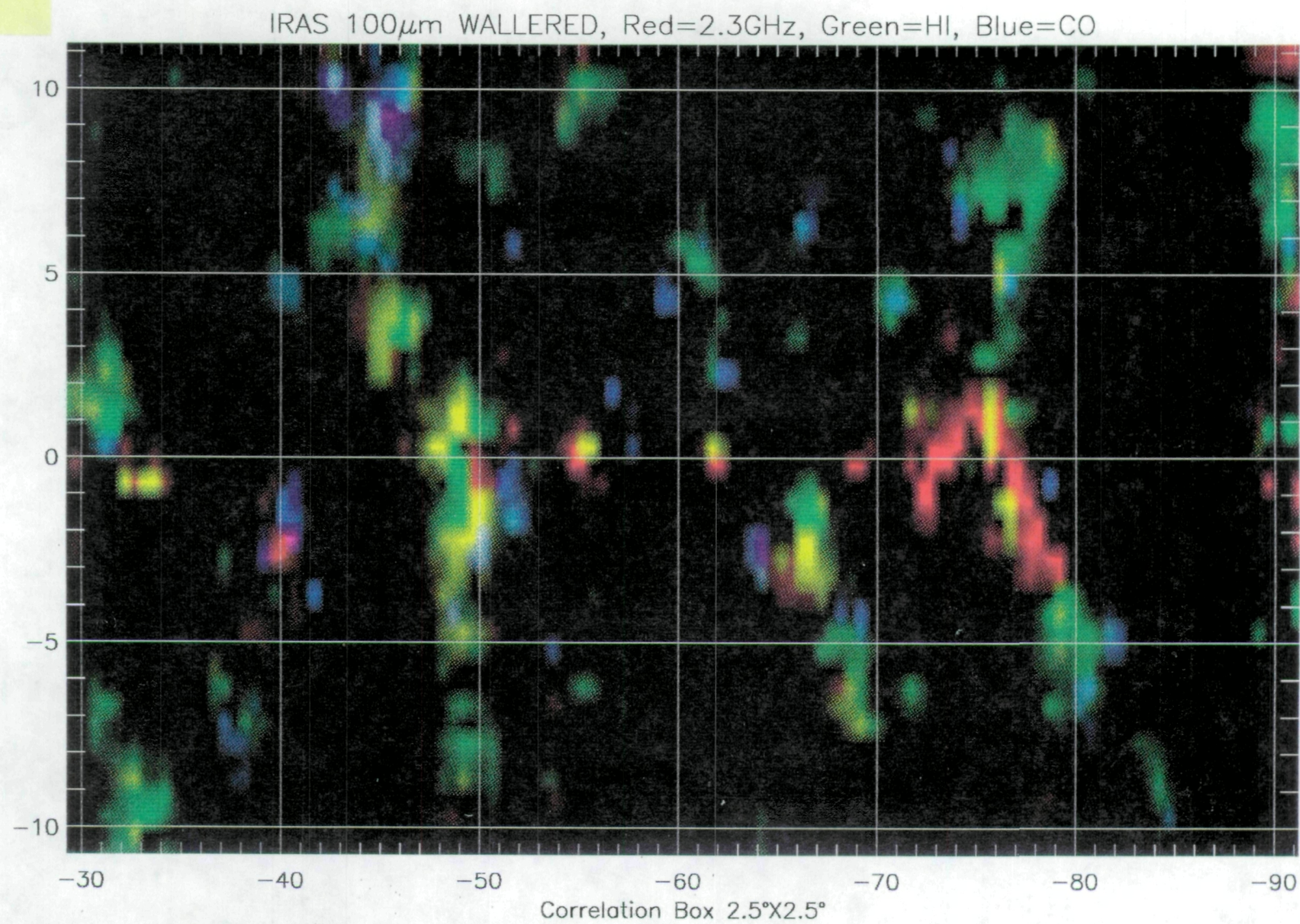


TABLE 2
INTERSTELLAR COUNTERPARTS TO 100 μ m FINE-SCALE STRUCTURE

No.	ℓ_{IJ}	b_{IJ}	RA(2000)	Dec(2000)	$\delta\ell_{IJ}$	δb_{IJ}	Rank(Cnm)	Rank(HI)	Rank(CO)
1.....	0.0	+0.0	17.76	-28.9	1.0	1.0	1	...	2
2.....	1.0	+10.0	17.18	-22.6	2.0	1.0	1	...	0
3.....	1.0	+4.0	17.55	-26.0	0.5	0.5	1	...	1
4.....	1.5	+6.0	17.44	-24.5	0.5	0.5	0	...	1
5.....	6.0	-1.5	18.08	-24.5	1.5	1.5	1	...	0
6.....	7.0	-4.0	18.28	-24.8	0.5	0.5	0	...	1
7.....	10.0	-10.0	18.77	-24.9	1.0	0.5	2	1	0
8.....	11.5	-4.5	18.46	-21.1	1.0	1.5	0	1	0
9.....	14.5	-2.0	18.40	-17.3	0.5	0.5	0	0	1
10.....	14.5	+0.5	18.25	-16.1	0.5	0.5	0	0	1
11.....	16.5	+3.0	18.17	-13.2	3.0	2.5	1	1	2
12.....	16.5	-3.5	18.56	-16.2	0.5	0.5	0	1	0
13.....	17.0	+8.0	17.88	-10.3	0.5	0.5	0	0	1
14.....	18.0	+10.5	17.77	-8.2	0.5	0.5	0	0	1
15.....	18.0	-8.5	18.92	-17.1	1.0	2.5	1	2	0
16.....	19.0	-0.5	18.46	-12.6	0.5	0.5	0	1	0
17.....	20.0	+6.0	18.10	-8.7	1.0	1.0	2	3	1
18.....	22.5	-1.5	18.63	-10.0	1.0	1.0	1	2	0
19.....	22.5	+9.0	18.00	-5.0	1.0	1.0	1	2	3
20.....	25.5	+9.0	18.10	-2.4	1.0	0.5	1	0	0
21.....	28.0	+3.5	18.50	-2.8	1.5	1.0	2	1	0
22.....	30.0	-0.5	18.80	-2.8	1.0	1.0	1	2	0
23.....	30.5	-3.0	18.96	-3.5	1.0	2.0	1	1	0
24.....	31.0	-6.0	19.16	-4.4	1.5	3.0	0	1	0
25.....	31.0	+1.5	18.71	-1.0	1.0	0.5	1	1	2
26.....	31.0	+4.0	18.56	+0.1	0.5	0.5	0	1	0
27.....	31.0	+7.0	18.38	+1.5	0.5	0.5	2	1	0
28.....	33.5	-9.5	19.44	-3.8	0.5	1.0	0	1	0
29.....	35.5	-1.5	19.02	+1.6	0.5	0.5	1	0	0
30.....	36.0	+1.0	18.89	+3.2	0.5	0.5	0	1	0
31.....	37.5	+0.5	18.97	+4.3	1.0	1.0	1	2	1
32.....	38.0	+3.5	18.80	+6.1	0.5	1.0	1	0	0
33.....	39.5	+2.5	18.91	+7.0	1.0	1.0	2	1	0
34.....	39.5	-1.5	19.15	+5.2	1.0	1.0	1	2	0
35.....	40.0	-4.5	19.34	+4.2	2.0	1.5	3	1	2
36.....	46.5	+5.5	18.94	+14.6	2.0	1.5	2	1	0
37.....	47.0	+10.0	18.68	+17.0	1.5	1.5	0	1	0
38.....	47.0	-6.0	19.65	+9.6	1.0	2.0	0	1	0
39.....	48.5	+0.0	19.34	+13.8	0.5	0.5	1	1	1
40.....	49.0	-9.5	19.92	+9.7	0.5	0.5	0	1	0
41.....	49.5	+1.0	19.31	+15.2	0.5	0.5	0	0	1
42.....	49.5	+2.0	19.25	+15.6	0.5	0.5	0	1	0
43.....	49.5	+3.0	19.19	+16.1	0.5	0.5	0	1	0
44.....	49.5	+9.0	18.81	+18.8	0.5	0.5	0	1	0
45.....	49.5	+10.5	18.72	+19.4	0.5	1.0	0	1	0
46.....	49.5	-9.0	19.91	+10.3	0.5	0.5	0	1	0
47.....	50.0	-3.0	19.57	+13.7	0.5	0.5	0	0	1
48.....	51.0	+0.5	19.39	+16.3	0.5	1.0	0	2	1
49.....	51.0	+3.5	19.21	+17.7	0.5	0.5	0	1	0
50.....	51.5	+3.0	19.25	+17.9	0.5	1.0	0	1	0
51.....	52.5	+2.0	19.35	+18.3	0.5	1.0	0	1	0
52.....	54.0	+7.0	19.08	+21.9	1.5	5.0	2	1	0
53.....	55.5	-10.5	20.20	+14.6	1.5	0.5	0	1	0
54.....	55.5	+4.0	19.32	+21.9	0.5	0.5	0	1	0
55.....	56.0	+5.5	19.24	+23.0	0.5	0.5	0	1	0
56.....	57.5	-7.5	20.10	+17.9	1.0	2.0	0	1	0
57.....	60.0	-8.5	20.25	+19.5	0.5	0.5	0	1	0
58.....	60.5	+0.0	19.75	+24.3	0.5	0.5	1	0	0
59.....	61.0	+10.0	19.11	+29.4	0.5	1.0	0	1	0
60.....	61.5	-2.5	19.94	+23.9	0.5	0.5	0	1	0
61.....	62.5	-1.0	19.89	+25.5	0.5	0.5	0	1	0
62.....	64.0	-4.0	20.13	+25.2	1.0	1.5	2	1	0
63.....	65.0	+8.0	19.38	+32.1	1.0	1.0	1	0	0
64.....	66.0	-2.0	20.09	+28.0	0.5	0.5	0	0	1

TABLE 2—Continued

No.	ℓ_{II}	b_{II}	RA(2000)	Dec(2000)	$\delta\ell_{II}$	δb_{II}	Rank(Cntm)	Rank(HI)	Rank(CO)
65.....	69.0	-9.5	20.68	+26.2	1.5	1.5	2	1	0
66.....	69.5	+1.5	20.00	+32.8	0.5	1.0	2	1	1
67.....	70.0	+4.0	19.85	+34.5	0.5	0.5	0	0	1
68.....	71.0	-6.0	20.55	+29.9	2.0	1.5	2	1	0
69.....	71.0	+2.0	20.03	+34.4	1.0	2.0	1	2	3
70.....	73.0	-2.5	20.42	+33.5	0.5	1.0	0	1	0
71.....	74.5	+7.0	19.82	+39.9	1.0	1.0	0	1	0
72.....	75.5	+0.5	20.34	+37.3	0.5	0.5	1	2	0
73.....	77.5	-3.5	20.71	+36.6	1.0	0.5	3	2	1
74.....	78.0	-2.0	20.63	+37.9	1.5	2.0	1	3	2
75.....	79.5	+1.5	20.47	+41.1	2.5	2.5	1	2	2
76.....	79.5	+7.5	20.01	+44.5	1.0	2.5	2	1	0
77.....	80.5	+8.5	19.98	+45.8	1.0	1.5	2	1	0
78.....	82.0	+7.0	20.17	+46.3	1.0	1.5	1	2	0
79.....	82.5	-2.5	20.91	+41.1	1.5	2.0	2	1	3
80.....	84.5	+0.5	20.81	+44.5	0.5	0.5	1	0	0
81.....	84.5	+8.0	20.22	+48.9	1.0	1.5	0	1	0
82.....	86.5	+5.5	20.55	+49.2	0.5	0.5	0	1	0
83.....	86.5	-8.0	21.50	+40.2	0.5	0.5	0	1	0
84.....	89.0	-9.0	21.72	+41.1	1.5	2.0	2	1	0
85.....	89.0	-2.5	21.31	+45.9	0.5	0.5	0	0	1
86.....	90.0	-0.5	21.24	+48.0	0.5	0.5	0	0	1
87.....	92.0	+2.0	21.19	+51.2	2.0	1.5	2	1	3
88.....	94.0	+0.0	21.49	+51.2	0.5	1.0	0	1	0
89.....	94.0	-4.5	21.80	+47.8	1.5	2.0	2	1	3
90.....	95.0	-1.5	21.68	+50.7	1.0	0.5	1	0	0
91.....	95.0	-10.0	22.20	+44.0	0.5	0.5	0	1	0
92.....	98.0	+9.5	21.00	+60.6	2.0	1.5	0	1	0
93.....	99.0	+5.0	21.52	+58.2	1.0	1.0	1	2	0
94.....	102.5	-3.5	22.46	+53.6	0.5	0.5	0	1	0
95.....	103.5	+2.0	22.20	+58.7	0.5	0.5	1	0	0
96.....	104.5	+1.0	22.38	+58.4	0.5	0.5	1	0	0
97.....	105.5	+0.0	22.55	+58.1	0.5	0.5	1	0	0
98.....	107.0	+5.5	22.33	+63.6	1.0	1.5	1	2	0
99.....	108.0	+8.5	22.19	+66.6	1.5	1.0	2	1	0
100.....	110.0	+2.0	22.96	+62.0	2.0	1.5	1	2	3
101.....	110.5	-4.5	23.35	+56.2	0.5	1.0	0	1	0
102.....	111.0	-2.0	23.30	+58.7	1.0	1.0	1	2	0
103.....	111.0	+4.5	22.94	+64.7	1.0	0.5	0	1	0
104.....	111.5	+9.5	22.62	+69.3	1.0	0.5	0	1	0
105.....	112.0	-2.0	23.42	+59.0	1.0	1.5	2	1	3
106.....	112.5	-6.0	23.63	+55.4	1.5	1.5	0	1	2
107.....	115.5	-9.0	0.04	+53.2	0.5	0.5	1	0	0
108.....	117.0	-5.0	0.12	+57.4	0.5	0.5	0	1	0
109.....	117.5	-9.0	0.25	+53.5	1.0	1.0	1	1	0
110.....	118.0	+4.5	0.02	+66.9	1.5	1.5	1	2	0
111.....	118.5	+2.5	0.16	+65.0	0.5	0.5	0	0	1
112.....	119.0	-2.5	0.33	+60.1	0.5	0.5	0	1	0
113.....	120.0	+0.0	0.43	+62.7	1.0	0.5	0	1	0
114.....	122.5	+3.0	0.79	+65.9	0.5	0.5	0	1	0
115.....	123.0	-6.0	0.87	+56.9	1.0	1.0	1	1	0
116.....	124.0	-3.5	1.00	+59.4	0.5	0.5	1	0	0
117.....	124.0	+0.5	1.02	+63.4	0.5	0.5	0	0	1
118.....	126.5	-9.0	1.25	+53.7	2.0	2.0	0	1	0
119.....	126.5	+1.0	1.39	+63.6	0.5	0.5	0	1	0
120.....	128.0	-4.0	1.50	+58.5	0.5	1.0	0	1	0
121.....	128.0	+9.0	1.91	+71.2	0.5	0.5	0	1	0
122.....	130.5	+9.5	2.42	+71.0	0.5	0.5	0	1	0
123.....	132.0	-1.5	2.08	+60.1	0.5	0.5	0	1	0
124.....	133.0	+9.5	2.87	+70.0	0.5	0.5	0	1	0
125.....	133.0	+7.5	2.71	+68.2	1.0	0.5	2	1	0
126.....	133.5	+1.0	2.39	+62.0	2.0	1.0	1	0	0
127.....	134.5	-0.5	2.44	+60.2	0.5	0.5	2	0	1
128.....	136.0	+2.0	2.77	+61.9	0.5	0.5	2	1	0
129.....	136.0	+4.0	2.90	+63.7	0.5	1.0	0	1	0
130.....	136.5	+1.0	2.77	+60.8	1.0	0.5	1	0	0

TABLE 2—Continued

No.	ℓ_{II}	b_{II}	RA(2000)	Dec(2000)	$\delta\ell_{II}$	δb_{II}	Rank(Cntm)	Rank(HI)	Rank(CO)
131.....	137.5	+1.5	2.93	+60.8	0.5	1.0	1	2	0
132.....	138.5	+5.0	3.30	+63.4	0.5	0.5	0	1	0
133.....	139.5	+3.5	3.30	+61.6	0.5	1.0	0	1	0
134.....	140.5	-0.5	3.14	+57.6	0.5	0.5	2	1	0
135.....	141.0	-1.5	3.14	+56.5	0.5	1.5	1	2	0
136.....	141.5	+3.0	3.49	+60.0	0.5	0.5	1	0	1
137.....	141.5	+1.0	3.35	+58.4	0.5	0.5	0	1	0
138.....	142.0	-5.5	3.01	+52.5	0.5	1.0	0	1	0
139.....	142.5	+0.0	3.39	+57.0	0.5	1.0	0	2	1
140.....	143.0	-5.5	3.11	+52.0	0.5	1.0	0	1	0
141.....	143.0	-1.5	3.34	+55.5	0.5	0.5	1	2	0
142.....	145.5	+7.0	4.25	+60.6	0.5	0.5	0	1	0
143.....	146.0	-0.5	3.69	+54.6	0.5	0.5	0	1	0
144.....	146.5	-7.5	3.31	+48.5	0.5	0.5	0	1	0
145.....	146.5	-10.5	3.15	+46.0	1.0	0.5	1	1	0
146.....	148.0	+6.0	4.39	+58.1	0.5	0.5	0	1	0
147.....	148.0	+0.0	3.91	+53.7	0.5	0.5	0	1	0
148.....	149.0	+0.0	3.99	+53.1	0.5	0.5	0	1	0
149.....	149.5	-4.5	3.73	+49.3	0.5	1.0	1	1	0
150.....	150.5	-4.0	3.84	+49.0	0.5	1.0	2	1	0
151.....	150.5	-0.5	4.08	+51.7	1.0	0.5	1	2	2
152.....	151.0	+4.5	4.51	+55.0	1.0	1.0	1	0	2
153.....	152.5	+4.0	4.58	+53.5	0.5	1.0	1	1	0
154.....	153.0	-6.0	3.91	+45.9	0.5	0.5	1	0	1
155.....	154.0	-4.0	4.11	+46.8	0.5	0.5	0	1	0
156.....	154.5	+2.0	4.57	+50.7	0.5	0.5	0	1	0
157.....	154.5	+5.0	4.81	+52.7	0.5	0.5	0	1	0
158.....	155.5	+10.5	5.38	+55.1	0.5	0.5	0	1	0
159.....	158.0	-10.0	4.01	+39.7	3.0	1.0	2	1	0
160.....	161.5	-8.0	4.34	+38.7	0.5	0.5	0	1	0
161.....	163.5	+6.5	5.48	+46.3	1.0	1.5	0	1	0
162.....	165.5	+8.5	5.74	+45.7	0.5	0.5	0	1	0
163.....	166.5	-4.0	4.88	+37.7	0.5	1.0	0	1	0
164.....	167.5	-7.0	4.74	+35.0	1.5	1.5	0	1	0
165.....	169.5	-10.0	4.66	+31.6	0.5	0.5	0	2	1
166.....	170.0	+1.0	5.39	+37.9	0.5	0.5	0	1	0
167.....	171.0	+1.5	5.48	+37.3	0.5	1.5	0	1	0
168.....	171.0	-2.5	5.20	+35.0	0.5	1.5	1	2	3
169.....	171.5	+1.0	5.46	+36.6	0.5	1.0	3	2	1
170.....	172.5	+0.0	5.44	+35.3	1.5	1.5	1	2	0
171.....	173.0	+3.0	5.67	+36.5	2.0	1.5	1	2	0
172.....	173.0	-2.0	5.33	+33.7	1.0	0.5	1	0	0
173.....	175.5	-9.5	4.98	+27.3	1.0	0.5	0	1	0
174.....	175.5	-7.5	5.10	+28.5	0.5	0.5	0	1	0
175.....	176.0	+9.5	6.26	+37.1	1.0	1.0	0	1	0
176.....	176.5	+6.0	6.03	+35.0	0.5	0.5	0	0	1
177.....	177.0	+9.0	6.26	+36.0	0.5	0.5	0	1	0
178.....	178.0	+10.5	6.41	+35.7	1.0	0.5	0	1	0
179.....	178.0	+1.0	5.75	+31.2	0.5	0.5	0	1	0
180.....	178.0	-9.5	5.09	+25.3	0.5	0.5	0	1	0
181.....	178.5	+4.5	6.00	+32.5	0.5	0.5	0	1	0
182.....	179.0	+7.5	6.23	+33.5	0.5	0.5	0	1	0
183.....	179.0	-6.0	5.34	+26.5	1.0	1.0	0	1	1
184.....	179.0	-2.0	5.59	+28.7	0.5	1.5	2	0	1
185.....	179.5	+10.5	6.46	+34.4	0.5	0.5	2	1	0
186.....	180.0	+11.0	6.52	+34.2	0.5	0.5	1	0	0
187.....	180.0	+10.0	6.44	+33.8	0.5	0.5	1	0	0
188.....	180.0	+8.0	6.30	+32.9	0.5	1.0	1	0	0
189.....	180.0	-2.5	5.60	+27.6	0.5	0.5	0	0	1
190.....	180.0	-7.5	5.29	+24.8	0.5	0.5	1	0	0
191.....	181.0	-6.0	5.42	+24.9	0.5	1.0	0	1	2
192.....	181.0	-4.5	5.51	+25.7	0.5	0.5	0	1	0
193.....	181.5	-2.0	5.69	+26.6	0.5	0.5	0	1	0
194.....	182.0	-7.0	5.40	+23.5	0.5	1.0	0	1	0
195.....	182.0	-5.0	5.52	+24.6	0.5	1.0	0	1	0
196.....	182.0	+7.0	6.30	+30.6	0.5	0.5	0	1	0

TABLE 2—Continued

No.	ℓ_{11}	b_{11}	RA(2000)	Dec(2000)	$\delta\ell_{11}$	δb_{11}	Rank(Cntm)	Rank(HI)	Rank(CO)
197.....	182.5	+0.0	5.86	+26.8	0.5	0.5	0	1	0
198.....	182.5	-6.0	5.48	+23.6	0.5	0.5	0	1	0
199.....	183.0	-7.5	5.41	+22.4	0.5	0.5	0	1	0
200.....	183.0	-5.5	5.53	+23.5	0.5	1.0	1	2	0
201.....	183.0	-3.5	5.66	+24.5	0.5	0.5	0	1	0
202.....	184.0	-3.0	5.73	+24.0	0.5	0.5	1	0	0
203.....	187.0	+6.0	6.41	+25.8	1.0	0.5	1	0	0
204.....	188.5	+7.0	6.53	+24.9	0.5	0.5	0	1	0
205.....	189.0	+3.5	6.32	+22.8	1.5	2.0	1	1	2
206.....	189.0	+1.5	6.19	+21.9	0.5	0.5	1	2	3
207.....	189.5	+0.5	6.14	+21.0	1.0	0.5	1	2	0
208.....	191.0	+2.5	6.32	+20.6	1.0	1.0	2	1	3
209.....	191.0	+10.5	6.84	+24.2	0.5	0.5	0	1	0
210.....	191.0	+9.5	6.77	+23.8	0.5	0.5	0	1	0
211.....	192.0	+0.0	6.20	+18.5	1.0	1.0	2	1	0
212.....	192.0	-9.0	5.66	+14.0	1.0	0.5	0	1	0
213.....	193.0	-1.5	6.14	+16.9	1.5	1.5	1	2	0
214.....	194.0	-7.5	5.81	+13.1	1.0	1.0	0	0	1
215.....	194.0	+6.0	6.64	+19.6	0.5	1.0	1	1	0
216.....	194.5	-4.5	6.01	+14.2	0.5	1.0	2	1	0
217.....	196.0	-5.0	6.03	+12.6	0.5	1.0	0	1	0
218.....	196.0	-1.5	6.24	+14.3	0.5	0.5	0	1	0
219.....	196.5	-3.0	6.17	+13.2	0.5	0.5	0	1	0
220.....	197.0	-4.0	6.12	+12.2	0.5	1.0	0	1	0
221.....	198.5	-9.5	5.85	+8.3	0.5	0.5	0	0	1
222.....	200.0	-10.5	5.84	+6.5	0.5	0.5	0	1	0
223.....	201.0	-10.0	5.90	+5.9	0.5	0.5	2	0	1
224.....	201.0	+2.0	6.61	+11.5	0.5	1.0	0	1	1
225.....	202.0	-8.5	6.02	+5.7	0.5	0.5	0	0	1
226.....	202.0	+4.5	6.79	+11.8	0.5	0.5	2	1	0
227.....	202.5	+2.0	6.66	+10.2	1.0	1.5	1	2	3
228.....	203.5	-10.5	5.95	+3.5	0.5	0.5	0	0	1
229.....	204.5	+2.5	6.75	+8.6	1.0	0.5	0	2	1
230.....	204.5	+1.0	6.66	+8.0	0.5	0.5	2	1	0
231.....	206.0	+1.5	6.74	+6.9	0.5	0.5	1	1	1
232.....	206.0	-0.5	6.62	+5.9	0.5	0.5	1	1	1
233.....	206.5	-2.0	6.54	+4.8	2.5	2.0	1	0	0
234.....	207.0	-4.5	6.41	+3.2	0.5	1.0	3	1	2
235.....	208.0	-6.0	6.35	+1.6	0.5	1.0	0	1	0
236.....	208.5	-4.5	6.46	+1.9	0.5	0.5	0	1	0
237.....	209.0	-1.0	6.68	+3.0	0.5	0.5	0	0	1
238.....	209.0	+2.5	6.89	+4.6	1.0	0.5	0	1	2
239.....	209.5	+6.0	7.11	+5.8	0.5	0.5	0	1	0
240.....	210.0	-3.0	6.59	+1.2	0.5	1.0	1	2	0
241.....	211.0	-0.5	6.77	+1.5	0.5	0.5	1	0	0
242.....	211.0	+2.5	6.95	+2.9	1.0	0.5	1	0	1
243.....	211.0	+6.5	7.19	+4.7	1.0	0.5	0	1	0
244.....	212.0	+6.5	7.22	+3.8	1.0	0.5	0	1	0
245.....	212.5	+8.5	7.35	+4.2	0.5	0.5	0	1	0
246.....	212.5	+0.5	6.87	+0.6	0.5	0.5	1	2	0
247.....	213.0	-5.0	6.56	-2.3	0.5	0.5	0	1	0
248.....	214.5	+7.0	7.32	+1.8	0.5	0.5	0	1	0
249.....	214.5	+10.0	7.50	+3.2	0.5	0.5	0	1	0
250.....	215.5	+8.0	7.41	+1.4	0.5	1.0	0	1	0
251.....	217.0	-10.5	6.35	-8.3	0.5	0.5	0	1	0
252.....	217.5	+0.5	7.03	-3.8	0.5	0.5	0	0	1
253.....	218.5	-8.0	6.55	-8.6	0.5	0.5	1	0	0
254.....	219.0	-10.0	6.44	-9.9	0.5	0.5	1	2	0
255.....	220.0	-10.5	6.44	-11.0	1.0	0.5	0	1	0
256.....	221.5	+1.0	7.18	-7.2	0.5	0.5	1	2	0
257.....	222.0	-6.5	6.74	-11.0	1.0	0.5	0	1	0
258.....	222.0	+2.0	7.25	-7.1	1.0	0.5	1	0	0
259.....	222.0	+9.0	7.67	-3.9	0.5	0.5	0	1	0
260.....	222.5	-4.0	6.91	-10.3	0.5	0.5	0	1	0
261.....	222.5	-1.5	7.06	-9.2	1.0	1.0	1	0	2
262.....	223.0	+3.0	7.34	-7.6	1.0	0.5	1	2	0

TABLE 2—Continued

No.	ℓ_{II}	b_{II}	RA(2000)	Dec(2000)	$\delta\ell_{II}$	δb_{II}	Rank(Cntn)	Rank(HI)	Rank(CO)
263.....	224.0	+0.5	7.23	-9.6	0.5	0.5	1	2	2
264.....	224.0	-1.5	7.11	-10.5	1.0	1.5	1	0	0
265.....	224.5	+9.0	7.75	-6.0	1.5	1.0	1	0	0
266.....	224.5	-3.5	7.00	-11.9	1.0	0.5	1	2	0
267.....	225.0	-5.0	6.93	-13.0	0.5	0.5	2	1	0
268.....	225.5	+10.5	7.87	-6.2	0.5	0.5	0	1	0
269.....	226.0	-8.0	6.77	-15.2	0.5	0.5	0	1	0
270.....	226.5	+5.0	7.58	-9.7	1.0	1.0	0	1	2
271.....	228.5	+7.0	7.76	-10.5	1.5	2.0	0	1	2
272.....	230.5	+7.0	7.83	-12.2	1.5	1.5	0	1	0
273.....	230.5	+2.0	7.53	-14.6	0.5	0.5	0	1	0
274.....	230.5	+0.5	7.44	-15.3	1.0	1.0	2	1	3
275.....	233.5	+3.0	7.69	-16.8	0.5	0.5	3	1	2
276.....	234.0	+0.5	7.55	-18.4	2.0	2.0	2	1	3
277.....	234.0	-5.5	7.18	-21.2	1.0	0.5	0	1	0
278.....	235.5	-4.0	7.32	-21.9	0.5	0.5	0	1	0
279.....	235.0	+3.0	7.74	-18.1	0.5	0.5	0	1	0
280.....	236.0	-10.5	6.91	-25.2	1.0	0.5	2	1	0
281.....	236.5	-5.0	7.29	-23.2	0.5	0.5	2	1	0
282.....	236.5	-2.0	7.48	-21.8	1.0	1.0	1	2	2
283.....	236.5	+3.0	7.79	-19.4	0.5	0.5	0	0	1
284.....	236.5	+4.5	7.88	-18.6	1.0	1.5	0	1	0
285.....	237.0	-3.5	7.40	-23.0	0.5	0.5	0	0	1
286.....	238.0	-7.5	7.18	-25.7	0.5	2.5	2	1	0
287.....	238.0	-3.0	7.47	-23.6	0.5	1.0	0	1	0
288.....	238.0	+4.5	7.94	-19.9	1.0	0.5	2	1	0
289.....	239.0	-3.5	7.47	-24.7	0.5	1.5	0	1	0
290.....	240.0	+8.0	8.22	-19.7	0.5	0.5	2	0	1
291.....	242.5	+8.0	8.32	-21.8	0.5	0.5	0	1	0
292.....	245.5	+1.5	8.04	-27.8	0.5	0.5	1	0	0
293.....	248.0	+5.0	8.36	-28.0	1.5	2.0	0	1	0
294.....	248.5	-5.5	7.69	-34.0	1.0	1.0	2	1	0
295.....	248.5	-3.0	7.86	-32.7	0.5	0.5	0	1	0
296.....	249.0	-8.0	7.53	-35.6	1.0	1.0	1	2	0
297.....	250.0	-10.5	7.38	-37.6	0.5	0.5	1	0	0
298.....	250.0	-4.0	7.85	-34.5	0.5	0.5	2	1	0
299.....	250.5	-5.5	7.77	-35.7	0.5	1.0	0	1	0
300.....	250.5	-9.0	7.51	-37.4	0.5	1.0	2	1	0
301.....	251.0	-7.5	7.64	-37.1	2.0	0.5	1	1	0
302.....	251.0	+8.5	8.71	-28.4	0.5	0.5	0	1	0
303.....	251.5	-4.5	7.88	-36.1	1.0	1.0	2	1	0
304.....	252.5	-8.5	7.63	-38.9	0.5	0.5	1	0	0
305.....	253.0	-1.5	8.15	-35.8	0.5	0.5	1	0	0
306.....	253.0	-5.0	7.91	-37.6	0.5	0.5	1	1	0
307.....	254.0	+0.5	8.34	-35.5	1.0	0.5	2	3	1
308.....	254.0	-9.5	7.61	-40.7	1.0	1.0	2	1	0
309.....	254.5	+9.5	8.93	-30.5	0.5	1.0	0	1	0
310.....	255.5	+8.0	8.89	-32.2	1.0	0.5	0	1	2
311.....	256.0	+9.5	9.00	-31.6	0.5	0.5	0	1	0
312.....	257.5	-1.5	8.36	-39.5	0.5	0.5	0	1	0
313.....	258.0	+7.0	8.95	-34.7	1.0	1.0	0	1	2
314.....	258.5	-3.5	8.27	-41.5	0.5	0.5	0	1	0
315.....	259.5	+6.0	8.97	-36.5	0.5	1.0	2	1	0
316.....	259.5	+8.5	9.13	-34.9	0.5	1.0	0	1	2
317.....	260.0	+9.5	9.21	-34.6	0.5	0.5	0	1	0
318.....	260.0	-4.0	8.31	-43.0	0.5	0.5	0	1	0
319.....	260.0	-2.0	8.46	-41.8	0.5	0.5	1	0	0
320.....	261.0	-4.5	8.32	-44.1	0.5	0.5	1	0	1
321.....	261.0	+2.5	8.82	-39.9	0.5	0.5	0	1	0
322.....	261.0	+6.0	9.05	-37.6	0.5	0.5	0	1	0
323.....	261.0	+7.0	9.12	-37.0	1.0	0.5	2	1	0
324.....	262.0	+1.5	8.81	-41.3	1.0	1.5	1	0	2
325.....	263.0	-0.5	8.73	-43.3	1.0	0.5	1	0	0
326.....	263.0	-8.0	8.14	-47.7	0.5	0.5	2	0	1
327.....	263.0	+4.0	9.04	-40.5	0.5	1.0	2	1	0
328.....	263.5	+3.0	9.00	-41.5	1.0	1.0	1	1	0

TABLE 2—Continued

No.	ℓ_{II}	b_{II}	RA(2000)	Dec(2000)	$\delta\ell_{II}$	δb_{II}	Rank(Cntrn)	Rank(HI)	Rank(CO)
329.....	264.5	+2.0	8.99	-42.9	0.5	0.5	1	1	0
330.....	264.5	-8.0	8.22	-48.9	1.0	2.5	2	1	3
331.....	265.5	-7.0	8.36	-49.2	0.5	2.0	2	1	0
332.....	265.5	+10.0	9.56	-38.1	0.5	0.5	0	1	0
333.....	266.0	+3.5	9.18	-43.0	0.5	0.5	0	1	0
334.....	267.0	-9.5	8.23	-51.8	1.0	1.0	1	2	0
335.....	267.5	-1.0	8.96	-47.1	1.0	1.0	0	1	2
336.....	268.0	-6.0	8.60	-50.7	1.0	1.0	2	1	0
337.....	268.5	+7.5	9.60	-41.9	2.5	3.5	3	1	2
338.....	269.0	-3.0	8.91	-49.6	0.5	2.0	0	1	1
339.....	270.0	+10.0	9.84	-41.0	1.0	0.5	1	0	0
340.....	270.5	-0.5	9.20	-49.0	0.5	0.5	1	0	0
341.....	270.5	+0.5	9.27	-48.3	0.5	0.5	2	1	0
342.....	271.0	-4.5	8.92	-52.1	0.5	0.5	0	1	0
343.....	276.0	-8.5	8.93	-58.4	1.0	1.5	0	1	2
344.....	278.0	-5.0	9.43	-57.5	0.5	0.5	0	1	0
345.....	279.5	+10.5	10.57	-46.0	0.5	0.5	0	1	0
346.....	278.5	-5.5	9.43	-58.2	2.0	2.0	2	1	0
347.....	281.0	-3.0	9.87	-58.0	0.5	0.5	1	0	0
348.....	281.5	-0.5	10.11	-56.3	0.5	0.5	0	0	1
349.....	281.5	+8.5	10.64	-48.8	1.0	1.5	2	1	0
350.....	282.5	-2.0	10.10	-58.1	0.5	1.5	1	0	0
351.....	283.5	-1.5	10.24	-58.3	1.0	1.5	1	2	0
352.....	283.5	+4.5	10.61	-53.2	1.0	2.0	2	1	2
353.....	284.0	-2.0	10.26	-59.0	0.5	0.5	1	0	0
354.....	284.0	+7.5	10.82	-50.8	1.5	1.0	0	1	0
355.....	284.0	+10.5	10.95	-48.1	0.5	0.5	0	1	0
356.....	284.5	+1.5	10.54	-56.3	1.0	1.0	1	2	0
357.....	284.5	+3.0	10.63	-55.0	0.5	0.5	0	1	0
358.....	285.5	+0.0	10.55	-58.1	0.5	0.5	0	1	0
359.....	286.0	+6.5	10.96	-52.6	1.0	1.0	0	2	1
360.....	286.5	+0.5	10.69	-58.2	1.0	1.0	1	0	0
361.....	286.5	+3.5	10.86	-55.5	0.5	0.5	1	0	0
362.....	286.5	+8.0	11.08	-51.4	0.5	0.5	0	0	1
363.....	287.5	+9.0	11.22	-50.9	0.5	0.5	0	1	0
364.....	288.0	+0.0	10.84	-59.3	1.0	2.0	1	2	0
365.....	288.5	-6.5	10.44	-65.2	1.0	0.5	0	1	0
366.....	289.0	+4.0	11.16	-56.1	1.0	1.0	0	1	2
367.....	291.0	-0.5	11.17	-61.0	0.5	0.5	1	0	0
368.....	291.0	-6.0	10.83	-66.0	1.5	2.0	2	1	2
369.....	294.5	-2.5	11.55	-64.1	1.5	2.0	2	1	0
370.....	294.5	+6.5	11.87	-55.4	1.0	1.0	0	2	1
371.....	295.0	+3.5	11.84	-58.4	0.5	0.5	0	1	0
372.....	296.0	-10.5	11.34	-72.1	0.5	1.0	0	1	0
373.....	296.0	-3.0	11.75	-65.0	1.0	1.0	2	3	1
374.....	298.0	+0.0	12.14	-62.5	0.5	0.5	1	1	0
375.....	298.0	+2.5	12.20	-60.0	1.0	0.5	0	2	1
376.....	298.0	+4.0	12.23	-58.5	0.5	0.5	0	1	0
377.....	299.0	+5.5	12.38	-57.2	1.0	1.0	0	1	2
378.....	300.5	+4.5	12.55	-58.3	0.5	0.5	0	0	1
379.....	302.5	+0.5	12.80	-62.4	0.5	0.5	0	0	1
380.....	302.5	+1.5	12.80	-61.4	0.5	0.5	0	0	1
381.....	303.5	+2.0	12.94	-60.9	0.5	0.5	0	0	1
382.....	305.0	-1.5	13.18	-64.3	1.0	0.5	0	1	0
383.....	305.0	+0.0	13.16	-62.8	1.0	0.5	1	2	0
384.....	305.0	+10.0	13.08	-52.8	1.5	1.5	2	1	0
385.....	306.5	-9.0	13.60	-71.6	0.5	0.5	2	1	0
386.....	306.5	-7.0	13.54	-69.6	0.5	0.5	1	0	0
387.....	306.5	-5.0	13.48	-67.6	0.5	0.5	0	0	1
388.....	307.5	+0.0	13.52	-62.5	0.5	0.5	0	1	0
389.....	308.5	-2.0	13.72	-64.3	1.0	1.0	0	0	1
390.....	308.5	+1.0	13.64	-61.4	0.5	0.5	1	0	0
391.....	308.5	+6.0	13.53	-56.4	0.5	0.5	0	0	1
392.....	310.0	-1.5	13.92	-63.5	1.0	1.5	2	1	3
393.....	310.0	+8.0	13.66	-54.2	1.0	1.0	0	1	0
394.....	310.5	-8.0	14.32	-69.6	1.5	1.5	0	1	0

TABLE 2—Continued

No.	ℓ_{II}	b_{II}	RA(2000)	Dec(2000)	$\delta\ell_{II}$	δb_{II}	Rank(Cnum)	Rank(HI)	Rank(CO)
395.....	311.0	-5.0	14.23	-66.6	1.5	1.5	2	1	0
396.....	311.0	-2.0	14.09	-63.7	1.5	2.0	2	1	0
397.....	311.0	+1.5	13.96	-60.3	1.0	1.0	2	1	0
398.....	312.5	+0.5	14.19	-60.9	0.5	0.5	2	1	0
399.....	312.5	+1.5	14.15	-59.9	0.5	0.5	2	1	0
400.....	313.5	+3.5	14.19	-57.7	0.5	1.0	2	1	0
401.....	313.5	+10.0	13.98	-51.5	0.5	1.0	3	2	1
402.....	314.0	+0.5	14.38	-60.4	0.5	0.5	1	0	0
403.....	315.0	+4.0	14.35	-56.8	1.0	2.0	2	1	3
404.....	315.0	+8.0	14.20	-53.0	1.5	2.0	2	1	3
405.....	317.5	+6.5	14.52	-53.5	1.5	2.0	0	1	2
406.....	317.5	+10.0	14.38	-50.3	0.5	1.0	2	3	1
407.....	318.5	-4.0	15.22	-62.5	0.5	0.5	0	0	1
408.....	320.0	-2.0	15.25	-60.0	1.0	...	2	0	1
409.....	320.0	+4.5	14.87	-54.3	1.0	0.5	0	2	1
410.....	320.5	-4.5	15.50	-61.8	0.5	0.5	0	1	0
411.....	321.0	-1.0	15.30	-58.6	0.5	0.5	1	0	0
412.....	321.5	-7.5	15.88	-63.6	1.0	1.0	0	1	2
413.....	322.5	-8.0	16.04	-63.4	0.5	0.5	0	0	1
414.....	323.0	-3.0	15.65	-59.2	0.5	0.5	0	1	0
415.....	323.5	-6.0	15.96	-61.2	0.5	1.0	0	1	0
416.....	325.5	-10.5	16.61	-63.0	0.5	0.5	0	1	0
417.....	325.5	+10.5	15.07	-46.5	0.5	0.5	0	1	0
418.....	326.5	-9.5	16.60	-61.6	1.0	0.5	0	1	0
419.....	326.5	-0.5	15.81	-55.1	0.5	0.5	1	2	0
420.....	328.0	-9.5	16.73	-60.5	1.0	1.0	2	1	0
421.....	328.0	-0.5	15.94	-54.1	0.5	0.5	1	2	0
422.....	329.0	-2.0	16.14	-54.6	1.0	1.0	0	1	0
423.....	329.0	+2.0	15.85	-51.5	1.5	2.0	2	1	3
424.....	330.0	+1.5	15.97	-51.3	0.5	1.0	2	1	0
425.....	332.0	-1.0	16.31	-51.8	1.0	1.0	1	2	3
426.....	332.0	+2.5	16.06	-49.2	1.0	1.0	1	2	0
427.....	332.0	+5.0	15.89	-47.3	0.5	0.5	0	1	0
428.....	333.0	-3.5	16.58	-52.8	0.5	1.0	0	1	0
429.....	333.5	+9.5	15.74	-42.9	0.5	0.5	0	1	0
430.....	335.5	+8.5	15.93	-42.4	0.5	0.5	0	1	0
431.....	336.5	+8.0	16.03	-42.1	0.5	1.0	0	0	1
432.....	337.0	+0.5	16.56	-47.2	1.0	0.5	1	0	1
433.....	337.5	-1.5	16.74	-48.1	0.5	0.5	1	0	0
434.....	338.0	+0.0	16.66	-46.8	0.5	0.5	1	0	0
435.....	338.5	-5.0	17.07	-49.5	1.5	1.0	2	1	3
436.....	338.5	+7.5	16.19	-41.2	1.0	1.0	0	1	0
437.....	339.0	-3.0	16.95	-47.9	0.5	0.5	1	0	0
438.....	339.0	-0.5	16.76	-46.3	0.5	0.5	0	0	1
439.....	339.5	+4.0	16.48	-42.9	1.5	1.0	1	3	2
440.....	340.5	-3.5	17.08	-47.1	1.0	1.0	2	3	1
441.....	340.5	+9.5	16.20	-38.4	1.0	1.0	2	0	1
442.....	341.5	-5.5	17.29	-47.4	0.5	1.0	1	1	0
443.....	341.5	+3.0	16.66	-42.1	0.5	1.0	0	1	0
444.....	342.0	-3.5	17.16	-45.9	0.5	0.5	1	0	0
445.....	342.0	+6.5	16.47	-39.4	1.0	0.5	1	0	0
446.....	344.0	+10.0	16.37	-35.6	1.0	1.0	0	1	0
447.....	345.0	+1.5	16.97	-40.4	1.0	1.0	1	0	0
448.....	346.0	+7.0	16.66	-36.1	0.5	1.0	0	1	0
449.....	346.5	-5.5	17.55	-43.3	0.5	0.5	0	1	0
450.....	347.0	-9.5	17.90	-44.9	0.5	0.5	0	1	0
451.....	347.0	+6.0	16.78	-36.0	0.5	0.5	0	1	0
452.....	348.0	+8.5	16.68	-33.7	1.0	1.0	0	1	0
453.....	348.5	-1.0	17.32	-39.1	0.5	0.5	1	0	0
454.....	350.0	-1.0	17.39	-37.9	0.5	1.0	0	...	1
455.....	350.5	+8.0	16.83	-32.1	1.0	0.5	1	...	0
456.....	351.5	-3.0	17.60	-37.7	0.5	0.5	0	...	1
457.....	352.0	+10.5	16.75	-29.4	0.5	1.0	1	...	0
458.....	353.0	+1.0	17.40	-34.3	0.5	1.0	1	...	2
459.....	353.0	+2.0	17.33	-33.7	1.0	0.5	1	...	0
460.....	354.0	+5.5	17.15	-30.9	0.5	0.5	1	...	0

TABLE 2—Continued

No.	ℓ_{II}	b_{II}	RA(2000)	Dec(2000)	$\delta\ell_{II}$	δb_{II}	Rank(Cnm)	Rank(HI)	Rank(CO)
461.....	356.0	+2.0	17.46	-31.2	1.0	2.0	2	...	1
462.....	357.0	-2.5	17.81	-32.8	0.5	1.0	1	...	0
463.....	357.5	-8.0	18.21	-35.1	1.0	1.5	1	...	0
464.....	357.5	-2.0	17.79	-32.1	1.0	0.5	1	...	0
465.....	358.0	+5.5	17.33	-27.6	0.5	0.5	0	...	1
466.....	358.5	-5.5	18.07	-33.0	1.5	1.0	1	...	0
467.....	358.5	-0.5	17.73	-30.5	1.0	1.0	1	...	2
468.....	359.5	+9.0	17.18	-24.4	0.5	0.5	1	...	0
468.....	359.5	+9.0	17.18	-24.4	0.5	0.5	1	...	0

. . . Appendix A : from "First Symposium on the Infrared Cirrus
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INTERSTELLAR FROTH: THE CIRRUS-LIKE FAR-INFRARED STRUCTURE NEAR THE GALACTIC PLANE

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ABSTRACT IRAS/BIGMAP mosaics of the inner Galaxy have been accessed and analyzed in terms of the interstellar structures that are traced by the FIR emission. Through spatial filtering techniques, we have been able to eliminate the strong gradient in brightness towards the Galactic midplane thus revealing a "froth" of diaphanous structure in the FIR emission with size scales as small as the $4' \times 4'$ resolution of the images. *This cirrus-like structure is not merely of local origin, but consists of both nearby and more distant features in the disk.* Efforts to find interstellar counterparts to the FIR "froth" are discussed.

INTRODUCTION

Since the launch of the Infrared Astronomy Satellite (IRAS) in 1983, we have learned that far-infrared emission pervades every quadrant of the Galactic sky (cf. Beichman 1987). Moreover, the emission is rich with structure, thus providing important clues to the content and dynamics of the dusty ISM. At high Galactic latitudes, overlapping wisps, tendrils, and knots of FIR emission highlight the so-called Infrared Cirrus (cf. Boulanger 1990). Recent investigations of these presumably local features have revealed strong associations with HI features — often at anomalous (blueshifted) velocities (Deul and Burton 1990; Burton *et al.* 1993). Some of the Infrared Cirrus features are also evident in deep surveys of CO emission (Heithausen *et al.* 1993), thus indicating their multi-phase nature.

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FINE-SCALE FIR EMISSION

Using the IRAS/BIGMAP mosaics of the inner Galaxy, we have applied a form of spatial filtering which completely eliminates the strong gradient in brightness towards the Galactic midplane. The resulting images reveal a "froth" of diaphanous structure in the FIR emission with size scales as small as the $4' \times 4'$ resolution limit (see FIGURE 1). This cirrus-like structure extends all the way down to the Galactic midplane. Moreover, it scales in intensity with the smoothly varying background, independent of latitude, thus indicating that the fine-scale residual emission is co-extensive with the smooth background. If the *cosecant b* behavior of the smoothly varying background is the result of observing an edge-on disk of emitting dust, then the fine-scale residual emission originates from dust features that are similarly distributed. *Therefore, this cirrus-like structure is not merely of local origin, but consists of both nearby and more distant features in the disk.*

Although we had expected to find morphological evidence for supernova-driven "worms" or "chimneys" rooted in the Galactic plane (cf. Koo *et al.* 1992; Reach *et al.* 1993), our processing shows the FIR fine-scale structure to be more complex (e.g. less coherent and less rooted) as viewed in projection. This may be due to the varying distances and sizes of the emitting features. The observed *froth of superposed filaments, voids, and shells* has yet to be reconciled with other tracers of the ISM (see below).

INTERSTELLAR COUNTERPARTS

In an effort to determine the interstellar counterparts to the FIR "froth," we have compared the fine-scale FIR structure with maps of CO emission, local molecular clouds, and radio supernova remnants. FIGURE 1 shows these comparisons. The CO emission (from Dame *et al.* 1987) has been spatially filtered to bring out the fine-scale structure. The resulting CO emission residuals are shown as contours overlaying the FIR images. Correspondences between the FIR enhancements and CO residuals are evident close to the Galactic plane but disappear beyond a few degrees from the midplane. This is at least partly due to the limited dynamic range of CO intensities being emitted and/or detected. Deeper CO maps may reveal more structure at higher latitudes (e.g. Heithausen *et al.* 1993). In the mid-latitude Ophiucus star-forming region (not shown), we have found strong correlations between the CO and FIR emission (Boulanger and Waller 1993). Therefore, CO counterparts to the FIR fine-scale structure appear to be restricted to regions where the CO emission is strong — independent of latitude. Close to the plane, the strongest CO emission comes from the molecular ring at $R(\text{gal}) \approx 5$ kpc, implying a similar location for much of the midplane FIR fine-scale structure.

Comparisons with local molecular clouds (filled squares with error bars) show piecemeal correlation with the FIR enhancements. For example, the clouds comprising the Cygnus, Vulcan and Aquila complexes are poorly traced by the FIR residuals, perhaps because their dust is too cool for prominent emission at $100 \mu\text{m}$. Comparisons with radio supernova remnants (open circles with error bars) yield poor correlation with both the FIR *enhancements* and the FIR *voids*.

We suspect that the closest counterparts to the filamentary and shell-like FIR structures will be found in well-resolved maps of the Galactic HI and radio-continuum emission. At high latitudes, the Infrared Cirrus is most closely traced by HI features at specific velocities (Deul and Burton 1990; Burton *et al.* 1993). At intermediate latitudes, the HI emission shows an abundance of filaments and loop-like structures (Heiles 1984; Hartmann 1993), some of which could correspond to FIR features. And at low latitudes, some of the FIR "worms" have radio-continuum counterparts (Koo *et al.* 1992; Reach *et al.* 1993). Detailed comparisons between our images of the fine-scale FIR emission near the Galactic plane and similarly processed maps of Galactic HI and radio continuum emission should reveal many correlated features, whose measured properties could then be organized into a more coherent picture of the diffuse interstellar medium.

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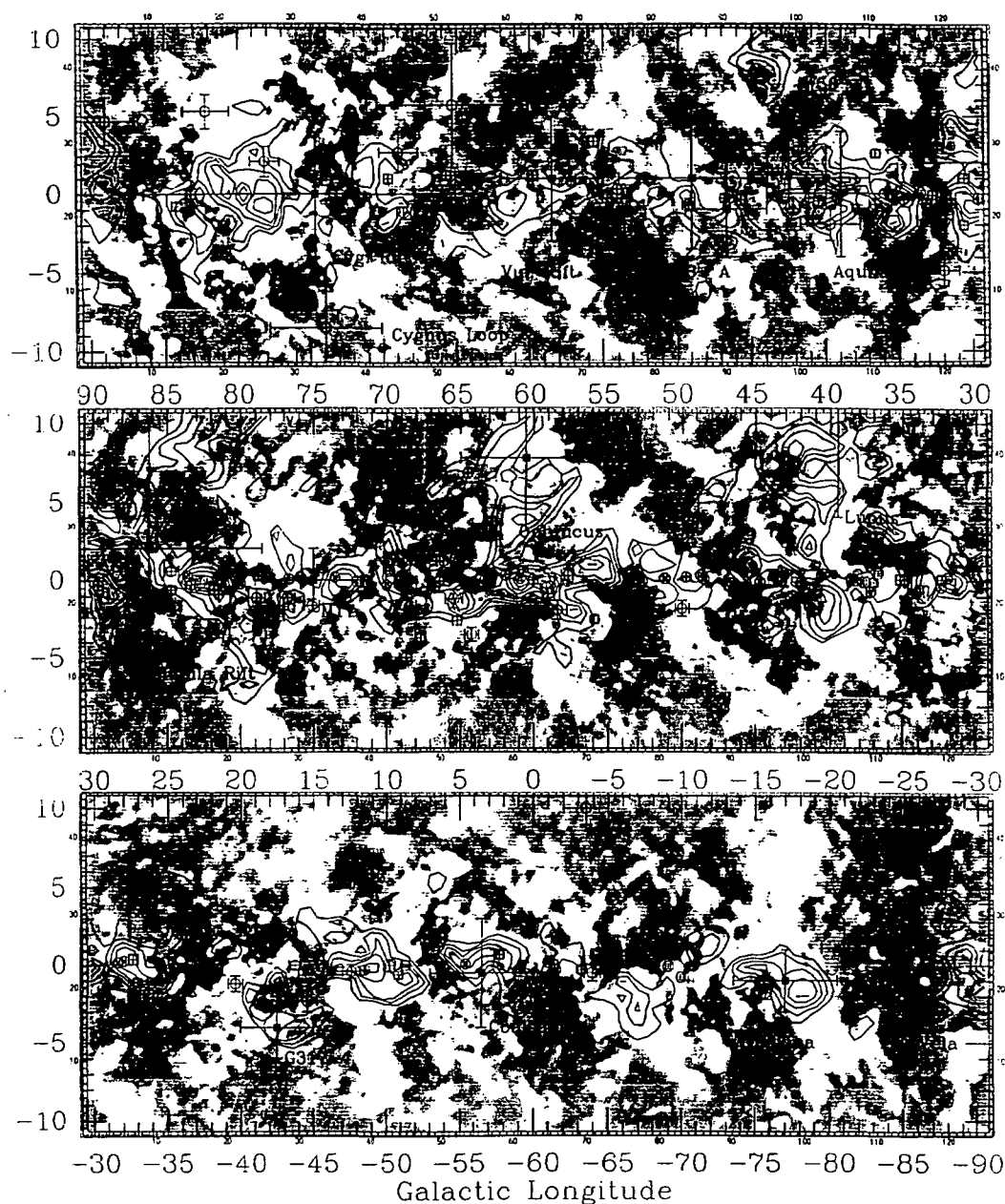


FIGURE 1. Far-infrared fine-scale structure in the inner Galaxy — from Cygnus (upper left), through the Galactic center (middle center), to Carina (lower right). Images are based on the IRAS/BIGMAP mosaics available from the IPAC. The *relative residual* emission at $100\ \mu\text{m}$ is shown, after having spatially filtered the original mosaics to eliminate the strong gradient in brightness towards the Galactic midplane. Contours of residual CO emission are overlaid along with the positions and sizes of local molecular clouds (filled squares [from Dame *et al.* 1987] and radio supernova remnants (open circles [from Green 1990])).



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